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CATALOGUE OF THE COLLECTIONS IN THE SCIENCE MUSEUM

SOUTH KENSINGTON

WITH DESCRIPTIVE AND HISTORICAL NOTES AND ILLUSTRATIONS

GEODESY AND SURVEYING

COMPILED BY

E. LANCASTER-JONES, B.A.

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PREFACE.

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The Science Museum, with its Collections and Library, aims at affording illustration and exposition in the fields of mathematical, physical, and chemical science, as well as their applications to astronomy, geophysics, engineering, and to the arts and industries generally. To that end the Museum includes objects which are of historical interest as marking important stages in development, and others which are typical of the applications of science to current practice.

A Museum of Science was contemplated as an integral part of the Science and Art Department from its beginning in 1853, and in 1857 collections illustrating foods, animal products, examples of structures and building materials, and educational apparatus, were brought together and placed on exhibition.

The first of the Engineering Collections, that of Marine Construction, was formed in 1864, when the Royal School of Naval Architecture was established at South Kensington, and the ship models belonging to the Admiralty were transferred to the Museum from Somerset House, where they had previously been. This collection of ships of war was of great historical interest, and with the assistance of private donors and by purchase it was rapidly increased by the addition of many models of mercantile ships as well as of later ships of war, with the result that when the Admiralty removed their models to the Royal Naval College, Greenwich, in 1873, an important collection still remained at South Kensington. Engineering and Manufactures were first included in 1867, from which time the development of this portion of the Museum advanced steadily; but the transfer of the Museum of the Patent Office to the Department of Science and Art in 1883 added to the collection many machines of the highest interest in the history of invention and greatly increased its scope and value.

The collections of scientific instruments and apparatus were first formed in 1874, but it was only after 1876 that they became of importance. The Special Loan Collection of Scientific Apparatus which was held in that year in London brought together examples of all kinds from various countries, and a large number of these were acquired for the Museum.

In 1893, many Mining and Metallurgical objects were transferred to South Kensington from the Museum of Practical Geology in Jermyn Street, and these have subsequently been largely added to.

Mention should be made, too, of certain special Collections: The Watt Collection was presented to the Patent Museum in 1876 and contains original models made by James Watt; the Maudslay Collection, consisting of models of marine engines and machine tools, was purchased in 1900; and in 1903 a valuable collection of engine models, portraits, etc., was bequeathed by Bennet Woodcroft.

The Museum Collections are being continually increased by gifts and loans, and also by the purchase of such examples as are required to illustrate the application of science and the development of various types of instruments, machinery, etc.

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Notes.—A large number of objects in the Collections have been photographed. Selected prints from the negatives may be seen in guard books at the entrance stiles. Particulars of available prints and lantern slides may be obtained by personal application at the entrances or by letter addressed " The Director, The Science Museum, South Kensington, S.W.7."

A compressed air service furnishes the power for driving such of the machines as are shown in motion, and the service is available daily from 11 a.m. (Sundays 2.30 p.m.) till closing time. Where practicable, these objects are fitted with self-closing air valves, by means of which Visitors may start them at will. Other objects are arranged so that Visitors may work them by other means, and there are a few that can be shown in motion only by an Attendant.

GEODESY AND SURVEYING.

CONTENTS.

(*The objects in the various Sections are arranged chronologically.*)

	Page
Marking Points :—	
Triangulation and Traverse Marks	9
Bench Marks	12
Beacons and Lamps	14
Direct Measurement of Distance :—	
Route Traversing	19
Field Measurement	22
Base Measurement	24
Indirect Measurement of Distance :—	
Rangefinding	28
Tacheometry	33
Measurement of Altitude :—	
Plummet Levels and Clinometers	38
Spirit Levels and Clinometers	40
Accessories	48
Barometers and Hypsometers	50
Measurement of Angles :—	
Fixed Angle Instruments	55
Plane Tabling	57
Compasses	59
Early Theodolites	64
Altazimuth Theodolites	68
Miscellaneous Instruments and Accessories	80
Geodetic Theodolites	83
Field Astronomy	86
Mine Surveying	90
Marine Surveying	95
Photographic Surveying	99
List of Donors and Contributors	105
Index	106
List of Museum Inventory Numbers of Objects with corresponding Catalogue Serial Numbers	109

LIST OF ILLUSTRATIONS.

Plate I.

		Page
Fig. 1.	Double-Mirror Heliotrope	15
Fig. 2.	Colby's Compensation Bars	

Plate II.

Fig. 1.	Early Balance Level	38
Fig. 2.	Spirit Level, by Cary	

Plate III.

Fig. 1.	Groma	56
Fig. 2.	Early Theodolite	

Plate IV.

Fig. 1.	Circumferentor, by Thos. Wright	67
Fig. 2.	Early Altazimuth Theodolite, by J. Sisson	

Plate V.

Fig. 1.	3-ft. Theodolite, by Ramsden	83
Fig. 2.	2-ft. Theodolite, by Troughton and Simms	

Plate VI.

Fig. 1.	12-in. Theodolite, by Watts	86
Fig. 2.	Transit, by Brauer	

Plate VII.

Fig. 1.	Equal Altitude Instrument, by Jobin	90
Fig. 2.	Lean's Dial, by W. & S. Jones	

CATALOGUE of the Collections in the Science Museum, South Kensington.

GEODESY AND SURVEYING.

Numerical references in the text refer not to the page but to the serial numbers placed at the beginning of each catalogue title. When an object is illustrated the reference to the plates of illustrations is given immediately after the title. The number at the termination of each description is that under which the object is registered in the Museum Inventory. If the objec has been photographed, the Inventory number is followed by the negative number.

GEODESY AND SURVEYING.

The term " geodesy " is usually applied to the task of determining the size and shape of the earth as a whole, whilst the name " surveying " is restricted to the processes used in fixing the position and dimensions of small portions of the earth's surface, and of the natural or artificial features located thereon. For many centuries geodesy has provided the foundation upon which more detailed surveys could be erected, and the methods and appliances employed in the two have differed only in precision. Consequently, in the collection representing geodesy and surveying, the arrangement and classification of the exhibits are designed to illustrate their essential inter-dependence, rather than to emphasize any differences which distinguish one from the other.

Historically and naturally, geodesy has been intimately associated with astronomy, and the instruments employed in the latter science have been applied with little modification to the former, and even, to a more limited extent, to surveying generally. The evolution of surveying instruments and processes can therefore only be properly appreciated by reference to the corresponding developments in astronomy, and particular attention may be called to the series of sundials, astrolabes, quadrants, sextants, reflecting circles, transits, etc., exhibited in the Astronomy collection. Many exhibits of geodetic interest will also be found in the collections representing Gravity and Terrestrial Magnetism, whilst in the Aeronautical collection a series of cameras of the types recently used for aerial surveying is exhibited.

MARKING POINTS.

Natural or artificial objects of a fairly permanent and prominent character, such as monuments or boundary stones, were the earliest station marks. The lack of precision in the surveying methods and instruments of the period would make any exact definition of the actual station point upon such objects unnecessary. In the early days of geodesy, church spires were favourite objects for observing upon ; the fact that they could rarely be occupied so as to observe from them did not seriously impair their value in this connection, for it was always possible to occupy some adjacent observing station and allow for the difference in position between the two. In comparatively uncivilised and sparsely populated countries, it was, and still is, usually necessary to erect an artificial signal which could be observed over a long distance. In the 17th century geodetic observations in Lapland and Peru, such signals were commonly made of timber built up into a conical or pyramidal shape and covered with brushwood or cloth ; space was left beneath the pyramid to permit of the erection of the observing instrument, so as to avoid the employment of satellite stations. Where possible, triangulation stations were permanently " marked " by means of stones buried in the ground, so that they could be re-occupied at any future date. Particular care was usually taken in marking the terminal points of bases. For example, the end points of the Hounslow Heath base in England were marked by means of iron pipes driven into the hubs of old coach wheels, buried in the ground ; these were replaced at a later date by iron cannon, buried mouth upwards, the centre of the bore indicating the exact terminal point. In the latter half of the 18th century, when the errors of observation due to refraction were noted, it became increasingly customary to observe at night time, and to use some form of luminous signal for such observations. In 1818 Gauss noted the powerful illumination obtained by reflecting the sun's rays by means of a mirror, and in 1820 devised a " heliotrope " (*see* No. 35) to utilize this fact in daylight observations. By using such luminous signals, sights could be taken over very long distances. The gradual improvement in the construction of lamps, of the Argand, acetylene and electric types, has caused these to be employed in the most precise work within recent years. Whenever opaque signals are now employed for daytime observations it is usual to allow space for the theodolite to be set up below the signal. In cases where observations cannot be taken at ground level, a stage is built up which serves both as a signal and an observing platform ; in such cases, it is customary to erect a separate stage for the observer to stand upon, so as to reduce the risks of disturbance of the observing instrument owing to vibration of the platform.

The actual points of a geodetic station are nowadays carefully marked in a permanent manner, usually by embedding a metal bolt in masonry or concrete, where no naturally fixed rock is available. Lines are engraved upon the metal bolt to define the exact station point. Such control points of a survey are generally buried beneath the ground, and reference marks placed to facilitate recovery of the control mark.

In surveys of minor precision, the signals are frequently ranging poles, fitted with parti-coloured flags or discs to facilitate observation. The marks at such stations are of a less elaborate and permanent

character than in geodetic work; iron pipes, wooden stakes with embedded nails, or occasionally, metal bolts set in concrete blocks at the surface of the ground form satisfactory marks in cadastral or engineering surveys.

TRIANGULATION AND TRAVERSE MARKS.

1. DIAGRAM OF TRIANGULATION MARKS OF THE ORDNANCE SURVEY. Made in the Museum.

The primary (first order) triangulation stations are now marked by means of a gun-metal bolt let into a block of concrete 2-ft. cube. The exact point is indicated by a small hole drilled in the top of the bolt, which is protected by an iron cover. The top of the block is at least two feet below the surface of the ground, except when set in solid rock. A cairn is built over the point when circumstances allow.

The secondary triangulation stations are marked in the same way, except that the dimensions of the block, bolt and cover are all less than in the case of the primary stations.

The tertiary stations are marked in the same way as permanent traverse stations. A brass bolt, having a cylindrical hole 7/16ths of an inch diameter drilled in its top, is cemented into a 30-in. iron socket, which is rammed into the ground until it is from 9 to 12 in. beneath the ground surface and then filled with concrete. Inv. 1920–388.

2. DIAGRAM OF TRAVERSE MARK OF THE ORDNANCE SURVEY. Made in the Museum.

To provide additional points for the control of the detailed survey, traverse lines are run between third or fourth order triangulation points with a theodolite by which, at each change of direction of the traverse line (traverse point), the azimuth of the forward line is measured.

All such traverse points in towns are now marked by means of a brass bolt, into the top of which can be fitted the 15-in. observing rod or the foot of the traverse pole. For temporary marks the bolts are cemented into the curb of the pavement. For permanent marks a 30-in. iron socket, similar to the base of an iron telegraph pole (Figs. 1 and 2) is rammed into the ground till the top is 9 to 12 in. below the surface. The socket is filled with cement or concrete, and the bolt cemented in at the top.

The number of points so marked varies according to the nature of the survey. In some continental cadastral surveys the average number is 20 to 50 per square kilometre in the country, and 100 to 150 in towns. In the highly cultivated land of Egypt where holdings are small but the land is level and unobstructed by hedges, about 16 to 20 per square kilometre are used. Inv. 1920–386.

3. TRAVERSE MARK BOLT AND COVER, ORDNANCE SURVEY. Presented by the Ordnance Survey.

A cylindrical hole 7/16ths in. diam. is drilled in the head of the bolt into which the 15-in. observing rod or the foot of the traverse pole can be fitted. The bolt is protected by an iron cap or hydrant cover according to the nature of the surface.

An observing pin and small circular spirit level for setting it vertical are also shown. Inv. 1914–154.

4. BRONZE TRIANGULATION MARK. Presented by the French Government.

This type of mark set either in rock or masonry is used for marking the first order triangulation stations in France. It consists of a small cylindrical bronze bolt with grooved sides and a cross engraved on its upper face, the intersection of the cross indicating the station point. Inv. 1914–107.

5. NAME-PLATE FOR TRIANGULATION MARK. Presented by the French Government.

This elliptical metal plate is fixed in masonry at a first order triangulation station in France, and carries a number corresponding to the particular station point. Inv. 1914–108.

6. TRIANGULATION STATION MARK. Presented by the U.S. Coast and Geodetic Survey.

This mark consists of a brass disc and shank cast in one piece. The shank is ribbed so as to grip securely the material—generally rock or concrete—in which the mark is set. One such mark is set at the surface and a similar one about 3 ft. directly underneath it at every triangulation station.

The station point is defined by a small dot within a 20 mm. equilateral triangle engraved on the disc.

(*See* U.S. Coast and Geodetic Survey Special Publication No. 26, p. 42.)

Inv. 1920–81.

7. MAGNETIC STATION MARK. Presented by the U.S. Coast and Geodetic Survey.

This mark is the older form of station mark used by the U.S. Coast and Geodetic Survey. Its shank is split so that a wedge can be inserted. When the mark is driven into the drill-hole, the wedge causes the shank to bulge and grip firmly the surrounding material.

The station point is defined by a dot enclosed in two intersecting 20-mm. equilateral triangles engraved on the disc.

(*See* U.S. Coast and Geodetic Survey Special Publication No. 26, p. 42.)

Inv. 1920–82.

8. HYDROGRAPHIC STATION MARK. Presented by the U.S. Coast and Geodetic Survey.

This mark is the same as that used for triangulation station marks, except that the central hole or dot is here surrounded by a 2·5-cm. circle. The mark is set in a post or block of concrete, or wedged into a drill-hole in rock, after which a triangle or circle is chiselled round it.

For underground station marks a similar disc is set 3 ft. below ground in a block of concrete, in rock or other suitable material.

(*See* U.S. Coast and Geodetic Survey Special Publication No. 26, pp. 42–43.)

Inv. 1920–78.

9. REFERENCE MARK. Presented by the U.S. Coast and Geodetic Survey.

This mark also consists of a metal disc and shank and is used to facilitate the recovery of station marks, especially where these are liable to damage or disturbance. The mark is placed so that the arrow engraved thereon points to the station mark, and the horizontal distance between the station mark and the groove cut across the shaft of the arrow is recorded.

Reference marks are set in concrete posts or blocks, or in rock, at distances up to 20 yd. from the station marks.

(*See* U.S. Coast and Geodetic Survey Special Publication No. 26, pp. 42–43.)

Inv. 1920–77.

10. TRIANGULATION STATION MARK. Presented by the Geodetic Survey of Canada.

Stations of the Primary Triangulation of Canada are marked by means of circular metal bolts of the type exhibited, the bolts being embedded in concrete or leaded into rock. Both underground and surface marks are employed, and reference monuments provided to facilitate recovery of the station.

The bolt consists of a 3-in. circular bronze disc, attached to a 3-in. cylindrical shank, which is corrugated and fox-wedged so that the shank expands tightly against the sides of the hole drilled to receive it when the bolt is driven in. The centre of the disc has a triangle engraved upon it, with a central hole punched to define the exact station point. Inv. 1922–726.

11. REFERENCE MARK. Presented by the Geodetic Survey of Canada.

Where the station marks of the Primary Triangulation of Canada are in danger of disturbance, or are difficult to find, reference marks of the type shown are set in outstanding rocks or in concrete monuments. Where possible, three such marks are set approximately 120° apart around the station.

The mark is a similar bronze bolt to the station mark, but has an arrow engraved upon it to indicate the direction in which the station point lies.

Inv. 1922–724.

12. REFERENCE MONUMENT PLATE. Presented by the Geodetic Survey of Canada.

Where no natural rock is available, reference monuments are built by the Geodetic Survey of Canada to mark the station points. Such monuments are erected in convenient places, preferably near a road, and a plate of the type shown is embedded into them.

The plate is rectangular and has two projecting shanks for fixing it into the monument. Inv. 1922–725.

13. GEODETIC TRIANGULATION STATION MARK. Presented by the Survey of Egypt.

This brass bolt forms the station mark at a geodetic station of the Survey of Egypt. It is provided with two saw-cuts intersecting at right angles, and is cemented into a concrete block in the ground. Accurately centred over this and built into the concrete block is an iron cylinder filled with concrete, having gaps in the bottom so that the mark can be seen. A brass and cast iron tribrach (*see* Cat. No. 14) is accurately centred over the mark and cemented in the top of the pillar. Upon this tribrach the theodolite rests when sighting from the station, whilst to its centre is screwed a heliograph or lamp when sighting to the station. Inv. 1920–630.

14. SELF-CENTRING GEODETIC STATION TRIBRACH. Presented by the Survey of Egypt.

This brass tribrach is built into a masonry pier and accurately centred over the concealed mark at geodetic stations in Egypt. It has three radial V-shaped grooves at angles of 120° with one another, and forms a self-centring stand for the three feet of a theodolite or signal lamp. Such a device is especially convenient in countries where the centring of signal lamps over the station point cannot always be entrusted to skilled operators. Inv. 1920–627.

15. DIAGRAM OF TRAVERSE LINES AND MARKS. Survey of Egypt, Qaliub District. (Scale 1 : 20,000.) Made in the Museum.

In the Cadastral Survey of Egypt, the method of traversing with theodolite and chain is used to control the detail chain survey, and this traverse system is connected up to the points of the minor triangulation system, the actual traverse lines being chosen to conform so far as possible to the village boundaries. The azimuths of these lines are measured with a 5-in. vernier theodolite, and their lengths with 20-m. steel chains. There are about 15 traverse stations per square kilometre.

In the diagram, which shows a portion of the Qaliub district on a scale of 1 : 20,000, the second and third order triangulation system is shown in red, whilst the traverse lines and points are in black.

(*See* " The Cadastral Survey of Egypt "—Capt. H. G. Lyons, F.R.S.

Inv. 1920–384.

16. " DRAY " TRAVERSE MARK. Presented by H. Dray, Esq.

The liability of ordinary metal bolts and bars used as traverse marks in Egypt to removal, led H. Dray to devise this land-anchor type of mark, which is now successfully employed in the soft soil of the Nile Valley and elsewhere.

The mark consists of a conical iron cap securely attached to the head of a screw pile which is buried some 6 ft. below the ground and is connected to the cap by a $\frac{1}{2}$-in. steel cable. The cap has a central socket to receive the ranging rod and rests on a circular concrete block interposed between it and the ground.

In order to drive the pile into the ground, its flexible cable is enclosed in an iron pipe of suitable length. A nut threaded on the pile-head keeps this pipe pressed against the pile at its lower end, where the pipe and pile are notched so as to interlock. The two then form a rigid pile which is driven into the ground by rotating the pipe with the pipe-grips shown. When only the head of the pile remains above ground, the nut is unscrewed and the pipe withdrawn, the space round the cable being filled with rammed earth. The concrete block, about 1 ft. diameter by 4 in. thickness, has a central hole and is next fitted over the projecting pile-head, forming a firm bed for the cap, which is afterwards screwed on to the head by means of the keys shown. The adjacent diagram illustrates the process of fixing the mark in position. Inv. 1921–360.

BENCH MARKS.

17. DIAGRAM OF LEVELLING MARKS OF ANCIENT EGYPT. (*Circa* 2800 B.C.) Made in the Museum.

When excavating near the pyramid of Seneferu (III Dynasty) at Meidum in 1891, Sir W. Flinders Petrie uncovered four corner walls of crude brick built round the angles of a rectangular tomb structure known as a "Mastaba." On the inner faces, which were plastered and whitewashed, level lines were drawn in red at intervals of one cubit, and numbered to show the distance of each below the "ground level" (nfrw). The sloping black lines show the inclination of the outer face of the masonry "Mastaba."

The hieroglyphic inscriptions in red record that the line to which they refer is 3, 4 or 5 cubits below ground level.

(*See* "Medum," by W. M. Flinders Petrie, London, 1892, p. 12 and Plate VIII.)

Inv. 1920–385.

18. DIAGRAM OF FUNDAMENTAL BENCH MARK. Made in the Museum.

A number of fundamental bench marks have been fixed in the principal (first order) levelling lines in the British Isles for the purpose of verification from time to time. These bench marks are fixed in rock in order to ensure permanence and immunity from accidental disturbance. One visible mark and two concealed marks, the altitudes of which are accurately known, are provided.

A recess having been excavated in sound and unweathered rock, the two reference points A and B are set in a bed of concrete. Mark A is a dome-headed bolt of bronze; mark B is a polished flint selected as being unlikely to deteriorate in any way. A third mark, C, is a bronze dome-headed bolt bearing the words "height above datum," and the altitude in feet. This is set in a granite pillar which rises 12 in. above the ground, and on which the name plate D is fixed.

Examples of the bronze bolts A and C and the name plate D, and also of the coverplate protecting the two lower marks A, B, are shown near by. The upper mark C is used for all ordinary purposes of levelling, whilst the concealed marks serve to determine whether secular changes of level are in progress.

The distance between fundamental bench marks varies from 25 to 35 miles.

(*See* "The Second Geodetic Levelling of England and Wales, 1912–1921," p. 14, Plate X.—Ordnance Survey, 1921.) Inv. 1920–387.

19. BENCH MARK. First Order. Presented by the Ordnance Survey.

This bolt forms the upper reference point at a fundamental bench mark on the first order levelling lines of the Ordnance Survey. It is fixed in the top of a granite block forming a pillar 12 in. high, and is the mark for use in all ordinary circumstances, its level being recorded on the topographical maps.

Inv. 1914–152.

20. BENCH MARK. First Order. Presented by the Ordnance Survey.

This bolt forms one of the two concealed reference points at a fundamental bench mark of the Ordnance Survey. It is set in rock concrete 3 ft. below ground in a concrete recess 3 ft. square by 1 ft. 9 in. deep, and will be used when necessary to determine whether any secular changes of level are in progress.

Inv. 1914–151

21. BENCH MARK NAME PLATE. Presented by the Ordnance Survey.

This plate is affixed to the granite pillar of a fundamental bench mark of the Ordnance Survey. Inv. 1914–153.

22. COVER OF REFERENCE BENCH MARKS. Presented by the Ordnance Survey.

The cover is placed below ground in a fundamental bench mark chamber to protect the reference marks of the Ordnance Survey from interference or damage.

Inv. 1914–155.

23. SECONDARY BENCH MARK. Presented by the Ordnance Survey.

At intervals of about a mile between the fundamental bench marks of the Ordnance Survey, secondary marks are fixed on lines of first order levelling. These consist of a gun-metal plate set flush with the surface of a wall, and having an identification number cast on it. The reference point, to which the published altitude corresponds, is the top of the " broad arrow." In levelling, the foot of the levelling staff is brought to the same altitude as this point with the aid of a detachable bracket and a small spirit-level.

(*See* " The Second Geodetic Levelling of England and Wales, 1912–1921," p. 14, Plate XI.—Ordnance Survey, 1921.") Inv. 1914–149.

24. BENCH MARK BRACKET. Presented by the Ordnance Survey.

This adjustable bracket is used for supporting the levelling staff at a secondary bench mark on the lines of the first order levelling of the Ordnance Survey.

The bracket is hooked on to the bench mark, and the upper surface, upon which the levelling staff is placed, is made level and in agreement with the reference point by means of the adjusting screw and the spirit level.

Inv. 1914–150.

25. BENCH MARK BRACKET. Lent by the Ordnance Survey.

This bracket is an old type of angle iron used to support the levelling staff at an Ordnance Survey broad arrow bench mark. It has a short arm which is fitted into the horizontal groove engraved above the broad arrow, and a longer inclined supporting arm which abuts against the wall in which the mark was notched. A series of circular depressions are sunk in the upper face to receive the stud on the base of the staff, the lower level of the depressions being a horizontal plane passing through the centre line of the engraved groove. This type of supporting bracket was superseded by the modern one represented in the next example. Inv. 1914–423.

26. BENCH MARK BRACKET. Lent by the Ordnance Survey.

This modern type of bracket is used to support the levelling staff at a broad arrow bench mark of the Ordnance Survey. It is broader than the adjacent earlier type, and has an adjusting screw threaded through its inclined arm and a box level mounted on its horizontal arm ; the end of the screw butts against the vertical wall in which the mark is engraved, and the inclination of the upper arm can be adjusted level by turning the screw. The flat base of the metal shoe forming the end of the staff rests on a stud projecting from the top of the bracket, the top of the stud being level with the centre line of the mark when the bracket is horizontal. Inv. 1914–424.

27. BENCH MARK. Presented by the U.S. Coast and Geodetic Survey.

This brass disc is fixed with its face flush with the building in which it is set or with its stem vertical in rock or cement. The short line in the centre is placed horizontal and serves as the reference point.

(*See* U.S. Coast and Geodetic Survey Special Publication, No. 26, p. 117.)

Inv. 1920–76.

28. BENCH MARK. First Order. Presented by the French Government.

This mark is used at first-order stations of the Nivellement Général de la France. It consists of a metal bolt having a grooved shank and a rectangular plate head with a recess to receive a plate, on which the height of the station point is printed. The reference point is the top of a spherical boss on a horizontal platform which projects from the plate. Inv. 1914–109.

29. BENCH MARK. Second Order. Presented by the French Government.

This mark is fixed at second-order stations of the Nivellement Général de la France. It is a metal bolt with a grooved shank and cylindrical head ; on the top of the curved surface of the head is a small spherical boss, the top of which is the reference point. The height of this point is printed on a plate embedded in the cylindrical head. Inv. 1914–110.

30. BENCH MARK. First Order. Presented by the Survey of Egypt.

This mark consists of an iron bolt 21 cm. long with a hexagonal head 5 cm. thick and 11 cm. wide. It is cemented into a vertical wall or solid rock. The point of reference is the top of a bronze hemispherical stud 1 cm. high, on the top of the upper face of the head. Inv. 1920–628.

31. BENCH MARK. Second Order. Presented by the Survey of Egypt.

This mark is similar to the adjacent first order bench mark, except that it has a cylindrical head, of which the highest point is the reference point.
Inv. 1920–629.

32. BENCH MARK. Presented by the Geodetic Survey of Canada.

Bronze tablets of this type are used by the Geodetic Survey of Canada to mark the station points of the Precise Levelling Network.

The tablet is a circular disc of diameter 3 in., provided with a corrugated, fox-wedged shank 3 in. long, for fixing it into rock or concrete. The centre of the disc is engraved with a cross, and a number can be stamped on it with a die for reference to the record book, which contains the particulars of the corresponding station. Inv. 1922–723.

33. DIAGRAM OF BENCH MARKS. Survey of India. Made in the Museum.

The type of mark now employed in India varies according to the character of the neighbourhood. In towns or cities the standard bench mark is used, as being less liable to interference than the metal bolts employed in Europe. In places where there is an outcrop of hard rock, the mark is made on this and suitably protected, as in the centre diagram. The embedded type of mark is more suitable in country districts, where no ground-rock or permanent stone building is available.

The " standard " type of bench mark was first employed in 1904. It consists of a stone monolith of 2 ft. square section, 3 ft. high, set upon a foundation of concrete 6½ ft. square by 2 ft. deep. The top of the monolith is cut in the form of a frustrum of a pyramid, and terminates in a square of 3 in. side, the central point of which constitutes the mark. The date of construction of the monolith is engraved on it, together with the inscription " G.T.S. Standard Bench Mark," whilst the height of its reference point above sea-level at Karachi is engraved upon a stone slab embedded in a brickwork setting round the base of the monolith.

The bench-mark inscribed upon ground-rock is protected by a masonry column, closed at the top by means of a stone slab on which is engraved the inscription " G.T. Survey, Upper Mark." The " embedded " bench mark consists of a 4-in. iron pipe embedded in well-rammed earth about 2 ft. below the ground level. A brickwork arch on concrete abutments is built over this mark in order to distribute the weight of traffic passing near. Above this arch is more rammed earth surrounding a central brickwork well, closed by a stone cover with the usual inscription. This type of mark has only recently been introduced, the previous type of " embedded " mark being a cubical stone block buried with its upper face slightly below the ground level.

(*See* " Great Trigonometrical Survey of India," Vol. XIX, Chap. IV.)
Inv. 1920–389.

BEACONS AND LAMPS.

34. PHOTOGRAPHS OF TRIANGULATION BEACONS. Presented by Major G. G. Waterhouse, R.E.

These two photographs illustrate the construction of quadripod triangulation beacons at Ado Rock and Awba Hill stations during the survey of Southern Nigeria, 1910–12.

The beacons are formed of tree-trunks and branches built up into a four-sided pyramid, the upper part of which is roofed with brushwood to form a prominent land-mark, and at the same time to protect the surveying instruments when taking bearings from the station. A pole carrying at its upper end a white flag is fixed to the top of the beacon to render it more conspicuous. The right hand photograph shows the framework of the beacon built up, but the roof not yet added. The left hand photograph shows a completed beacon, with a heliograph, theodolite and plane table standing beneath it. The ground in the vicinity has been carefully cleared of obstacles to view. Inv. 1921–306.

Fig. 1. Double Mirror Heliotrope, p. 15.

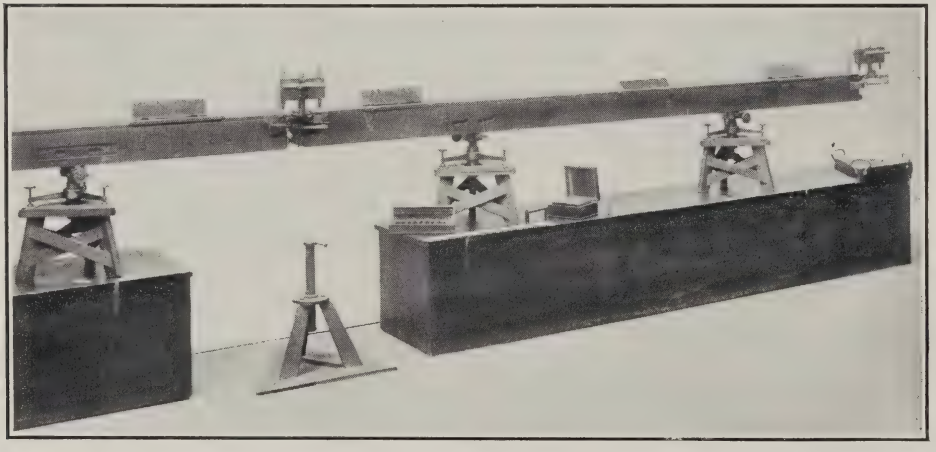

Fig. 2. Colby's Compensation Bars, p. 24.

35. SEXTANT-HELIOTROPE OR VIZEHELIOTROP. Made by Rumpf, Göttingen, 1827. Lent by the Admiralty.

In October, 1818, C. F. Gauss was observing at Luneburg, a station of the Altona-Hanover meridian arc, and noted in his observation book that the triangulation mark in Hamburg was difficult to see, but that the windows, lit up by the rays of the setting sun, facilitated the directing of his theodolite. This suggested to him the construction of a heliotrope, of which the sextant-heliotrope, made in 1920, was the first type.

The telescope is mounted on a circle capable of rotation about a horizontal axis, and can itself revolve about the centre of the circle. This circle has no divisions and is only for giving a slow motion to the telescope by means of a screw. Through a sleeve on the telescope passes a brass rod carrying a mirror perpendicular to it, the distances of the mirror and the sleeve from the axis of rotation of the telescope being equal.

In order to send a ray of sunlight in a specified direction, the instrument is set up so that the mark is in the centre of the field when the axis of the telescope is normal to the plane of the mirror. If, then, the telescope is directed to the sun and follows it continuously, the mirror will reflect its light on to the mark.

On account of its somewhat complicated form, this type of heliotrope was very shortly superseded by the adjacent double-mirror type.

(*See* Gauss, Werke, Bd. IX, pp. 461–484, and Poggendorff's Annalen der Physik, 1829, Bd. XVII, p. 83.)

Inv. 1914–305, S.M. 1935.

36. DOUBLE-MIRROR HELIOTROPE, OR SPIEGELKREUZ-HELIOTROP. Made by Rumpf, Göttingen, 1822. Lent by the Admiralty. Plate I, Fig. 1, p. 15.

C. F. Gauss, in writing to Schumacher in March, 1820, described this heliotrope as being more convenient, simpler, and having a larger reflecting surface than his sextant-heliotrope which it superseded. In its turn it was replaced by Bertram's heliotrope, which Bessel used on his East Prussian arc.

For use the telescope was directed on the triangulation mark, the small central mirror being turned parallel to the axis of the telescope. Then the double-mirror was turned until its axis was at right angles to a plane containing the sun, the instrument and the distant mark. This is facilitated by the disc beside the mirror, since, when its shadow is a line only, the mirror is in position. Lastly, the double mirror is rotated until the sun's image as reflected by the central mirror is seen in the telescope, when the outer mirror reflects the sun's light on to the distant mark.

(*See* Gauss, Werke, Bd. IX, pp. 461–483, and W. Jordan, Handbuch der Vermessungskunde, Bd. III, p. 33.) Inv. 1914–376, S.M. 1936.

37. HELIOTROPE. Lent by the Ordnance Survey.

This instrument, sometimes also called a heliostat, was used for reflecting the sun's rays to an observing station. Three sizes were in use by the Ordnance Survey in the principal triangulation ; the largest were rectangular and measured 20 in. by 16 in., the other two were circular and were 12 in. and 5 in. diam. respectively.

In each case the mirror, having been centred over the triangulation mark, was moved by hand so as to follow the sun and to reflect its light through a ring placed in the line between the heliostat, or the reflecting station, and the observing station. The ring was placed in position by means of a small theodolite.

Inv. 1914–425.

38. HELIOGRAPH. Presented by the Admiralty.

This instrument, primarily devised for signalling, can readily be used as a heliotrope at small distances ; the sighting arrangement is not suitable for long distances.

The instrument comprises a circular reflecting mirror of 4 in. diam., pivoted on horizontal bearings in a vertical frame, which is mounted rotatably in a vertical sheath projecting from a tripod head and can be clamped in the sheath by opposing screws. The mirror can thus be set in any desired plane and the reflected beam from the sun caused to fall upon a small sliding plate, which forms part of the foresight. This foresight is mounted on a sliding vertical rod at the end of a supporting arm, which is about 2 ft. long, and is pivoted horizontally to a vertical collar surrounding the sheath supporting the mirror. The arm can thus be pointed in the direction of the distant station and the

V-foresight accurately aligned by viewing through a central aperture left unsilvered in the back of the reflecting mirror. When the supporting arm has thus been directed, the sliding plate is moved over to the V to receive the reflected beam, and has an engraved dot accurately corresponding to the tip of the V-foresight. When the mirror is turned until the image of the sun falls on this plate, with the shadow caused by the unsilvered central hole of the mirror falling on the dot, the reflected beam is then directed towards the distant station.

A smaller mirror, of diam. 2½ in., can be substituted for the foresight rod if necessary owing to the sun's position. It also has a central unsilvered aperture for sighting.

The large mirror can be used apart from the stand, its socket having a bayonet joint to connect it to a small knife which is stuck into the ground.

Inv. 1911–155.

39. LESUERRE HELIOGRAPH. Made by Molteni, Paris. Lent by the School of Military Engineering, Chatham.

This instrument was primarily devised for long-distance signalling, but can be used for marking a distant station in triangulation. It is of the double-mirror type, and is provided with a sighting telescope and a smaller collimating telescope for adjusting the reflected beam of sunlight in the direction of the observing station.

The instrument consists of two elliptical plane mirrors, mounted upon a long arm which can rotate about a horizontal axis in the standard, the latter being furnished with the usual three levelling screws. The arm is provided with a spirit level clinometer and declination compass. Each mirror is so mounted on the arm that it can be set normal to any required direction, and has slow-motion tangent screws for accurate adjustment. There are two telescopes arranged so that their axes are always parallel to each other at a fixed distance apart but point opposite ways. The smaller telescope is directed towards the reflecting mirror, and, by means of it, the beam of sunlight reflected from this mirror projects upon a small screen, mounted at a suitable distance from its eye-piece end, an image of the sun and the cross-wires of the telescope. When the centre of the sun's image coincides with the intersection of the image of the cross wires, the axis of the telescope is parallel to the direction of the reflected beam. Hence the beam is directed parallel to the axis of the larger telescope, which is focussed on to the observing station, and the observer will see the flash of the heliograph. The necessary adjustments to effect this are made with the mirrors.

(*See* " Journal of Telegraph Engineers," 1878, pp. 351–355.) Inv. 1914–829.

40. ACETYLENE SIGNAL LAMP. Made in 1907 by E. R. Watts & Son. Lent by the Colonial Office.

This lamp is an acetylene projector designed by Mr. G. T. McCaw for use in trigonometrical surveys. It was first used in the measurement of an arc of meridian in Uganda, and later in the Royal Siamese Survey Department.

Its light can normally be seen at a distance of 30 miles. It is provided with a telescope for directing the beam, and with means for attachment to a rough table so as to be in the direct line between the observer and the mark at its own station.

The lamp is of ordinary motor design, with a separate carbide container, the gas being conveyed to the burner by flexible tubing. In the barrel is a single lens of about 5-in. aperture, movable slightly along the barrel for correct focussing.

The projector has independent traversing, azimuthal and vertical motions. When in use its lower plate is firmly screwed to a rough table in an approximate line between the station mark and the observer. Its orientation having been approximately corrected by the azimuthal and vertical motions, the projector is then accurately aligned by the traversing motion, operated by the handle on the left-hand side of the lower plate, and is clamped in this alignment. The axis of the barrel is then moved up or down, according to the indication of the telescope, by the vertical motion screw under the back of the barrel. This screw passes through the upper and middle plates, which are kept down to the lower plate by a spring and stop. Finally, the upper plate to which the barrel is rigidly attached, is swung in azimuth over the middle plate. When the telescope, attached to the upper plate, is directed on the observer's station, the upper plate is clamped by the wing nut under the front of the barrel. The axis of the projector is then correctly aligned on the distant station and the position of the burner is in the direct line between the local and distant triangulation points.

In the original form, a sighting tube affixed to the top of the barrel replaced the telescope.

For work by day a heliograph was attached to the front of the instrument, and projected its beam of sunlight through a hole cut in a board nailed to a post fixed from 10 to 20 ft. in front of the instrument. This was found less confusing to the native assistants in Rhodesia and Uganda than the mirrors of a self-contained heliograph such as is ordinarily employed in Army signalling.

Inv. 1914–238.

41. ELECTRIC SIGNAL LAMP. Presented by the Geodetic Survey of Canada.

This electric lamp is used at stations of the Primary Triangulation of Canada to mark the station point during night observations. It is visible at distances up to 130 miles.

The lamp is of the type used for motor-car headlights, and has a parabolic reflector behind the bulb. It is mounted within a wooden frame which can be supported upon the box within which it is packed for travelling, and can be adjusted upon this box by means of an elevating screw. The top of the frame has metal V-s attached to support the telescope used in aligning the lamp upon the observing station.

Two bulbs of different sizes are supplied with the lamp for use at smaller and larger distances respectively. They are illuminated by current supplied by a battery of dry cells. An electrically controlled time-switch can be connected in the circuit to light automatically the lamps at regular intervals. Inv. 1923–10.

DIRECT MEASUREMENT OF DISTANCE.

The direct measurement of length for the purposes of land and engineering surveys has undergone little modification since the earliest times of which we have records. In order to measure the distance between two points on the earth's surface, the ancient Egyptians marked out the straight line joining these points by means of a stretched cord (*see* No. 52), or by a set of intermediate pegs aligned by sighting. Graduated wooden rods or flexible cords were used as measuring units. Similar methods and appliances are still used in minor surveys and give results sufficiently accurate for ordinary purposes. The approximate estimation of distances by pacing, timing, or counting the revolutions of a wheel of known circumference was practised at a very early date, and such methods are still employed in reconnaissance and exploratory surveys. On the other hand, the precise measurement of length which is now a feature of trigonometrical or geodetic surveying had no counterpart in ancient or medieval times, but arose with the development of the general science of measurement in the 17th century.

Geodetic surveying entered upon its modern epoch with the arc measurements of Snell, about 1615, and Picard, about 1669. Snell, by introducing the method of triangulation from a fixed base, reduced length measurement to the minimum necessary to determine the base. As, however, any error in this base measurement inevitably affected the whole triangulation, the need for precision in its determination was evident; and the increasing accuracy of angle-measurement due to the application of the telescope to surveying instruments rendered a corresponding increase of precision in base-measurement necessary if the whole work were not to be vitiated. Consequently every effort was made to investigate the sources of error in base-measurement, and to minimize their effects. Amongst these sources, two were particularly prominent, namely, the variation of the effective length of the measuring units due to changes of temperature and the disturbance of one unit from its proper position when the next unit was placed in contact with it. As the measuring units employed were

made practically rigid, so as to avoid bending under gravity or the influence of wind, or stretching more or less premanently under tension, it was very difficult to measure the exact temperature of the units at the time of the observation, or to avoid some disturbance of one unit when its immediate successor was laid in position next to it. To reduce these " temperature " and " contact " errors, various devices were employed, and the measuring rods grew more and more complicated in consequence. Picard and his immediate successors had used wooden rods, tipped with brass. These rods were made about four fathoms in length, and were constantly compared during the measurement with copies of the standard " toise " or French fathom. In 1750, Boscovitch, when measuring the Rimini base in Italy, adopted the method of placing successive rods nearly but not quite in contact with one another, and measuring the intervals between them with beam compasses. This considerably reduced " contact errors," but the " temperature errors " remained relatively large, in spite of the small temperature coefficient of wood, until Borda, in 1792, utilized the unequal expansion of two metallic rods, similar in dimensions but made of different metals, to measure more exactly the mean temperature of either rod during the determination of the base.

This principle was utilized in a different manner in Colby's Compensation Bars (*see* No. 64), the object in this latter case being to provide a length which should be absolutely invariable whatever the temperature of the observation. The " metallic-thermometers " of Gauss and Bessel, used on the Hanoverian and Prussian arcs in the years 1820 and 1830–35, were similar to those used by Borda, but were placed so as to be separated by small intervals, which were measured by means of graduated glass wedges. Colby used double compensating microscopes, through which the terminal points of adjacent bars were viewed, to render the interval between each pair of bars exactly six inches. The Brünner apparatus, used until recently in France, Spain and other countries, is also similar to the Borda rod in employing the relative expansion of two metals to measure temperature changes, but in this apparatus, two independent measures of the base are made, one with each rod. Such an apparatus is termed a " bi-metallic " combination, and the Eimbeck Duplex base apparatus (*see* No. 67) is of this type, and was used on many geodetic bases in the United States previous to 1900. Contact disturbances are avoided in the Brünner apparatus by measuring the distances between microscopes, which are fixed at approximately equal distances along the base line. The measuring rod is provided with scales at its ends, and these are viewed in turn through each adjacent pair of microscopes. The Eimbeck apparatus is provided with a spring contact-slide to minimize disturbance, so that the end-pressure between adjacent bars is never big enough to disturb either. Experiments have been made with glass rods and ice-packed bars with a view to reducing temperature errors, but the invention of " invar " near the end of the last century has provided a metallic alloy whose temperature coefficient is so small as to render the exact determination of the temperature during a base measurement unnecessary.

The temperature errors are also considerably reduced by substituting a very thin tape or wire for the rigid rod of the older type of measuring unit, and thereby ensuring a more even distribution of temperature in the unit itself. The use of flexible as opposed to rigid measuring units originated with Jäderin about the year 1885, although

a flexible steel chain, made by Ramsden (*see* No. 61) had been used on the Hounslow Heath base in 1784 by General Roy, but in this case the chain was supported uniformly along its length. Jäderin, on the other hand, suspended his wires, of which two were used to measure each base independently, freely between fixed tripods, and measured the distance between each pair of tripods by means of scales engraved on the tapes (*see* No. 65). The two wires were of different metals, and thus formed a bi-metallic combination for determining the mean temperature during measurement, and they were stretched by a constant tension so that the sag could be calculated and allowed for. Invar tapes (*see* No. 69) or wires, either suspended freely between two tripods as in Jäderin's method, or supported at a few intermediate points on tripods carefully aligned with the two end ones, have superseded the rigid types of base apparatus in the most recent geodetic and topographical work. By means of these tapes, bases can be measured rapidly and accurately, and it is now a comparatively simple matter to measure "check" bases at frequent intervals in a long triangulation.

The various steel chains, bands, tapes, etc., used in land engineering and cadastral surveys require no general description. Examples of the usual types used in such work are exhibited. With regard to pedometers, etc., it is interesting to note that the invention of a mechanical counter for land and marine surveying is attributed to Hero of Alexandria, who is believed to have lived in the latter half of the 1st century A.D.

ROUTE TRAVERSING.

42. PEDOMETER. Early 18th Century. Presented by Evan Roberts, Esq.

This instrument, for registering the number of paces made by the person carrying it, resembles a watch in size, appearance and general details of construction. The "escapement" is, however, not actuated by a pendulum or balance wheel, but by a rocking lever and spring pawl which engages in a ratchet wheel.

The lever is depressed by the forward movement of the wearer's leg, which stretches a connecting cord attached to the split ring at the top of the instrument. This disengages the spring pawl momentarily and permits one tooth of the ratchet wheel to slip past its point. As the motion of the observer's leg slackens the tension in the cord, a counter spring forces the lever into its former position ready for the next forward movement. The ratchet wheel thus moves one tooth at every alternate stride of the wearer, and is connected with the pinion wheel train, dials and pointers which record the steps taken. There are four such dials and pointers, for the units, hundreds, thousands and ten thousands respectively, the units dial having 50 graduations and its pointer moving over one division every alternate pace of the observer. Inv. 1916–77.

43. PEDOMETER. Made by J. Alt, Berlin. Presented by Evan Roberts, Esq.

This is also an 18th century example, and has a similar construction and "escapement" to the preceding one. The cord which is attached to the observer's leg and actuates the rocking lever, is also exhibited ; it passes over a small pulley wheel mounted in the head of the pedometer.

The main dial in this instrument has its divisions numbered in two sets, and a pointer corresponding to each set. The outer set records the unit paces, and the inner set the tens. A second dial and pointer registers the thousands up to twelve. The units pointer moves over two divisions at a time, as it is only moved at every alternate step of the observer. Inv. 1916-82.

44. PEDOMETER. Made by Spencer & Perkins. Presented by T. MacNamara, Esq.

This is a late 18th century pedometer, of a construction less sensitive than the adjacent one by the same makers.

The rocking lever is here attached to a pin fitting across the top of the case, and the long hook is mounted upon the same pin, so as to embrace it tightly. As the hook is swung by the motion of the person carrying the instrument, the pin rotates and causes the lever to rock. A two-pronged spring pawl is fixed to the lever at its upper end and engages the teeth of a ratchet wheel at its lower end. As the lever rocks, the pawl causes the ratchet to slip a tooth, and thus turns a pinion wheel mounted on the same axis. The pinion gears in the train of wheels which record the paces taken. As only alternate paces are recorded, the dials and pointers are arranged accordingly. Miles and decimal parts of a mile are registered on three dials, the instrument recording up to 12 miles at intervals of one thousandth of a mile.

The long hook serves to suspend the pedometer from the fob so that it rests against the thigh, and thus gets the desired swing as the wearer walks.

Inv. 1911–182.

45. PEDOMETER. Made by Spencer & Perkins, London. Lent by F. G. Ogilvie, Esq., C.B.

This is probably a late 18th or early 19th century pedometer and differs from earlier examples in having a more delicate escapement, actuated by the sudden stoppage in the motion of the wearer's body at each step. The long hook is used to suspend the instrument from the fob of the person carrying it.

As usual the escapement is effected by the withdrawal of a spring pawl, attached to one end of a rocking lever, from the teeth of a small ratchet wheel. In this instrument the teeth are very fine, so that the pawl slips over four teeth at each oscillation. The lever is normally kept in the "down" position by a fairly strong spring, but the pull of this spring is considerably reduced by slightly raising the long hook projecting from the top. The lower end of this hook is fixed to a chain wound round a drum mounted on the same spindle as the rocking lever. The hook is raised when the instrument is fitted in its case by inserting a pin in a hole in the lower end of the hook, the ends of the pin resting in brackets on the top of the case. In this position, the rocking lever is just balanced, and is very sensitive to small jerks.

The instrument has three dials and pointers registering miles, tenths, and thousandths of a mile. The pointer of the thousandths dial is connected to the rachet wheel and so geared that it moves 176 times in one revolution, *i.e.* in one tenth of a mile.

The pedometer is mounted separately from its case for exhibiting the movement mechanism. Inv. 1912–200.

46. COMBINED PEDOMETER AND WATCH. Made by Ralph Gout, London. Presented by Evan Roberts, Esq.

This instrument was made about 1800 and consists of a pedometer and a watch mounted in the same case and having a common face, with separate dials and pointers. The pedometer movement is effected by the tension of a string, which is attached at one end to the wearer's leg, and at the other to a delicately poised rocking lever controlling by its oscillations the engagement of a spring pawl in a ratchet wheel.

The large pedometer dial is graduated to record every hundred double paces; there is a smaller one to register every ten double paces, and a third to record each double pace. Inv. 1916–83.

47. PEDOMETER MOVEMENT. Presented by Evan Roberts, Esq.

The movement here exhibited is of the type invented by W. Payne in 1831 and still used in modern pedometers. The escapement of the recording ratchet wheel is effected by the oscillations of a horizontal anchor-shaped pendulum, whose moment about its pivot is just more than balanced by the pressure of a control spring. The sudden jerk caused by the stoppage of the downward motion of the wearer's body at each step is sufficient to make the pendulum oscillate.

A spring pawl, fixed at one end to the pendulum arm, engages at its other end the teeth of the ratchet wheel. A counter spring pawl, pivoted in the bed of the instrument, opposes the thrust of the former with a force sufficient to damp the

rotary movement of the ratchet. (This opposing spring is missing in the instrument shown.) The teeth of the ratchet are very fine, so that as the pendulum moves from the upper stop to the lower, the pawl passes over several teeth, the number depending upon the adjustment of the lower stop, which is threaded in a fixed block. By this adjustment, the indication of the recording pinion can be varied to correspond roughly to the length of the observer's stride. The ratchet wheel is geared to a train of pinion wheels which record the distance travelled in miles and furlongs. There is only one dial and pointer, the former graduated in miles up to twelve, with eight sub-divisions to each mile. The numbering of the main graduations is like that used in watches.

(*See* British Patent Specification, 1831. No. 6078.) Inv. 1916–81.

48. PEDOMETER. Made by Pastorelli & Co.

This instrument has the movement invented by W. Payne in 1831 and shown in the preceding exhibit. The movement of the horizontal pendulum is restricted by stops, the lower one being adjustable to allow approximately for the variation in the length of stride.

The instrument is carried in the waistcoat pocket and kept in a vertical position by means of the spring clip attached to its ring. It has a single dial, graduated in miles and quarters up to 12 miles. Fractions of quarter-miles can be estimated by the position of the pointer between the graduations. Inv. 1875–25.

49. WAYWISER. Made by G. Adams. Lent by T. H. Court, Esq.

The Odometer, Waywiser or Perambulator has been employed since the days of the Romans for measuring distances by counting and recording the revolutions of a wheel of known circumference. The example shown was made in the late 18th century. It has a brass wheel of 1·5 ft. circumference geared to a registering mechanism furnished with dials and pointers which record the number of links, poles, chains, furlongs, and miles traversed.

The bearings for the wheel axle are fixed to metal brackets screwed to the case containing the registering mechanism, which itself is fixed at the lower extremity of a long wooden handle. At one end of the axle is a small pinion wheel the teeth of which engage in those of a perpendicular pinion mounted on the lower end of a brass rod, which is pivoted at its lower end in the axle bearing block and kept parallel to the supporting bracket by guides. The upper end of this rod is geared within the case to the registering mechanism. This has two pointers and dials, the outer one divided to read links and having divisions both every ten links and every pole, whilst the inner dial is graduated in miles and half furlongs up to four miles. Inv. 1914–895. S.M. 918. L.S.

50. PERAMBULATOR. Made by W. & S. Jones.

This instrument for measuring distances by recording the revolutions of a rolling wheel was made at the beginning of the 19th century, and is an improved form of the adjacent Waywiser, made by Adams. The wheel is much larger, its circumference being half a pole, and it is carefully mounted in its bearings so as to reduce friction and shake.

The mechanism differs slightly from that in the Waywiser. The motion of the rotating axle of the wheel is transmitted to a perpendicular shaft running along one bearing fork by a pair of bevel wheels, and from the shaft to the recording mechanism by a worm and worm-wheel. One of the bearing forks is hinged at the top to the case containing the recording mechanism. The outer dial has a diam. of 7 in. and is graduated in yards and poles, its pointer making one revolution every furlong. An inner dial, of 5 in. diam. is graduated in furlongs and miles up to 10 miles and is read by a second index.

The wheel and mechanism case are made of wood, with metal parts where there is much wear, *e.g.* the axle and bearings, wheel rim, etc.

(*See* Adam's " Geometrical and Graphical Essays," 1813.)

Inv. 1906–40. S.M. 939. L.S.

51. SLEDGE METER. Made by S. Smith & Son. Lent by the British Antarctic (Terra Nova) Expedition, 1910–13.

This form of measuring wheel was constructed specially for use on frozen snow surface and ice, and was employed on all journeys made by the above expedition when much reliance had to be placed on dead reckoning.

The instrument has a trailing wheel of diam. 18 in. made of steel, with an aluminium band on its rim to prevent snow from clinging to the surface and with steel pegs fitted into the rim so as to enable the wheel to roll without slipping on ice surfaces. The wheel is mounted in ball bearings upon a metal fork to which the recording mechanism is attached. The gearing is completely enclosed and the dial gives reading in geographical miles, subdivided to 25 yd. The fork is fixed to a wooden bar, to which at the other end is attached a cross head connected to the bar by a universal joint. This permits the instrument to follow the track of a sledge without partaking of its lateral movements. The instrument gave satisfactory readings over soft snow surfaces but registered too low on a very hard surface owing to the steel spikes giving a variable periphery.

Inv. 1914–111.

FIELD MEASUREMENT.

52. PHOTOGRAPH OF EARLY EGYPTIAN LAND MEASURERS. Presented by Captain H. G. Lyons, F.R.S.

Although no map of landed property in ancient Egypt has come down to us, representations of land measurers at work have been made upon tomb walls. This photograph shows the scene depicted upon the walls of the tomb of one Menna at Sheikh Abd el Qurna, in Thebes, a land overseer and inspector of the boundary stones of Amon (*Circa*, 1400 B.C.).

Two " chain " men, or " rope stretchers," are shown measuring a field of corn with a long cord on which are knots or marks at intervals apparently of 4 or 5 cubits ; each also carries a spare cord coiled up on his arm. Beside them walk three officials carrying writing materials and accompanied by a boy who also carries writing materials and a bag probably containing documents and plans relating to the property. An old man and two boys also accompany the surveyor and a peasant brings a loaf of bread and a bunch of green corn. In a similar scene pictured on the walls of a tomb belonging to a certain Amenhotep, also at Sheikh Abd el Qurna, it is possible to see that the measuring cord terminated in a ram's head.

(*See* " Cadastral Survey of Egypt," p. 50, Lyons, 1908.) Inv. 1913–572.

53. GUNTER'S CHAIN.

The chain most generally used in England for land measurement is named after its inventor, Edmund Gunter, and was first employed about 1620. It has a length of 66 ft. made up of 100 links, so that 10 square chains equal one acre.

The example shown is made of iron, with brass handles, as was formerly the custom. This type has been replaced by the chain made of steel wire, of No. 8 or No. 12 B.W.G., which stretches much less than an iron chain after use.

In all Gunter's chains, brass tellers are inserted at every 10 links, for convenience in estimating fractional lengths. Inv. 1872–78.

54. LAND SURVEYOR'S STEEL CHAIN. Made and lent by J. Chesterman & Co.

This chain, which is 66 ft. long and has 100 links, is representative of the modern land surveyor's chain. It is made of No. 12 B.W.G. steel wire, with brass handles, and brass tellers every 10 links. A central swivel is fitted to obviate kinks when the chain is twisted in use.

When not in use, the chain is folded up in the manner shown, and bound together with a leather strap. Inv. 1914–845.

55. STEEL MEASURING BAND. Made and lent by J. Chesterman & Co.

A steel band of this type is preferred to a chain by many land surveyors, partly because, length for length, it is lighter and also because it preserves its length much better after the strain of constant usage. On the other hand, it is not so durable as a chain, nor so easily read.

The example shown is 50 ft. long, and is divided every foot, the two terminal feet being subdivided into inches. The divisions are marked by brass studs of various sizes, an oval plate being substituted for the stud at every 10 ft. and marked by perforation to show the length from the nearer end. The handles are made of brass, with swivel joints. The whole is wound up in a metal case which has a narrow slit for inserting the handle at one end. A strap is attached to the case for carrying it.

The band is $\frac{5}{8}$ in. wide and of No. 26 B.W.G. thickness. Inv. 1914–846.

56. STEEL MEASURING TAPE. Made and lent by J. Chesterman & Co.

An accurately graduated steel tape of this type is extensively used for short measurements. This example is 10 m. long and is graduated throughout in millimetres. It is $\frac{3}{4}$ in. wide, and of No. 34 B.W.G. thickness. When not in use, it is wound up in the leather case as shown. Inv. 1914–847.

57. "QASSABA" MEASURING ROD. Presented by Captain H. G. Lyons, F.R.S.

The "qassaba" (*qassaba*, a rod, *Arabic*) is a Syrian unit of length which has been employed in land surveying in Egypt for the past ten or twelve centuries. Previous to a decree dated 1861, its actual length varied considerably at different times and in different parts of the country, but it was then defined as being equal to 3·55 m., the unit of area (feddan) then becoming 333⅓ square qassabas instead of 400. A "qassaba" rod, with its ends tipped with metal, is here exhibited, with photographs showing the rod in use.

The land-measurer (messah) holds the rod by the middle and places it successively along the line to be measured by turning it over on the forward end. Skilled "messahin" obtain remarkably good results but they can also easily vary the measurement towards excess or defect when turning over the rod. At the present time all official land-measurements in Egypt are made with the steel chain, but the qassaba-rod is still used in the villages for sub-dividing holdings or measuring up crops.

(*See* "The Cadastral Survey of Egypt," by Capt. H. G. Lyons, F.R.S.)
Inv. 1912–244.

58. WOODEN MEASURING RODS. Made by O. Fennel Söhne, Cassel.

Wooden rods (Messlatten, Messtangen) similar to the pair here shown are commonly used in Germany in land-measurement, and have been in use in Würtemburg for several centuries.

Each rod has alternate metres painted red and white, and each metre is subdivided by small studs into decimetres. They are made of well-seasoned fir, painted and varnished to prevent variations in length due to atmospheric moisture. The rods are usually round or oval in section and vary in thickness, tapering towards the ends, which are flat and tipped with metal. They are used of various lengths, 3, 4 or 5 metres being the most usual, and 2 metres in towns where narrow alleys occur. In measuring a length, the rods are used in pairs, being placed successively in contact and aligned on the distant point which is marked by a ranging rod.

(*See* Jordan's "Handbuch der Vermessungskunde," Bd. II, Section 18.)
Inv. 1914–257.

59. WOODEN MEASURING RODS. Made by O. Fennel Söhne, Cassel.

These are similar in general characteristics to the adjacent pair, but are of square section, and have wedge-shaped metal ends, which abut at right angles when the rods are laid in contact. In one rod the metres are painted alternately red and white; in the other, black and white. Each rod is 5 m. long, graduated in decimetres. Their length is verified before use by laying each rod on a test-bed provided with chisel-shaped stops at a known distance apart. By measuring the interval between the rod and the test-bed with a measuring wedge the length of the rod is obtained. Inv. 1914–258.

60. STEEL MEASURING WEDGE. Made by O. Fennel, Cassel.

In comparing a wooden measuring rod of the type used in cadastral surveys with the corresponding standard, it is usually necessary to measure very accurately the small distance between one end of the rod and the end of the standard. For this purpose, a steel measuring wedge of uniformly varying thickness is inserted between the two terminals. The one exhibited has a uniform variation in thickness of 1 mm. per 1 cm. of its length. Its length is graduated in millimetres, reading by estimation to tenth-millimetres, and thus giving the corresponding thickness to 0·01 mm., within a range of error of 0·01 mm.

(*See* "Handbuch der Vermessungskunde," Jordan, Bd. II, Section 20.)
Inv. 1914–259.

BASE MEASUREMENT.

61. STEEL CHAIN. Made by Ramsden. Lent by the Royal Society.

This chain was first used by General Roy in measuring the Hounslow Heath base in 1784. Although it was only used as a preliminary to more precise measurements with both fir and glass rods, General Roy was so impressed by its accuracy that, in measuring the base of verification on Romney Marsh in 1787, he used the chain only, and discarded the wooden and glass rods.

The chain has 100 links, each 1 ft. long. The joints at every 10 ft. are at right angles to the remainder, which permits the chain to be folded so as to fit into a box about 14 in. by 8 in. by 8 in. for transport. Brass plates are attached at the joints to indicate 10 ft. lengths along the chain.

In the rough measurement of the Hounslow Heath base, the chain appears to have been simply stretched along the ground, but in the measurement at Romney Marsh it was supported on deal coffers, 20 ft. long, resting on carefully aligned posts driven into the ground every 20 ft. along the base. Thus supported, the chain was stretched by a weight of 28 lb., the temperature being measured by thermometers laid in the coffers near the chain. Inv. 1900–156.

62. BONING TELESCOPE. Lent by the Royal Society.

In measuring the Hounslow Heath base in 1784, General Roy divided the base into sections of 200 yd., and erected tripods of fixed height for supporting the measuring rods at each division point; these sections were subdivided into segments of 20 ft., corresponding to the lengths of the deal measuring rods used, and intermediate tripods set up at the subdivision points with their platforms adjusted so as to be in the line connecting the platforms of the tripods at each end of the section. The telescope here exhibited was used to sight between the two terminal tripods upon boning rods set up at the subdivision points. The movable vanes of these rods being adjusted until their index lines lay on the axis of sight of the telescope, the height of the intermediate tripods was thus ascertained.

The telescope has a rack-focussing objective lens of 1·2 in. aperture and 13 in. focal length, and a fixed eyepiece of the Huygens type, with a fixed cross-wire diaphragm between the two lenses. The magnifying power of the eyepiece is small, and the telescope can be focussed down to a few feet. It has square brass collars shrunk on to its tube near each end to support it upon the platform of the tripod.

(*See* Phil. Trans. Roy. Soc., 1785.) Inv. 1900–157.

63. PHOTOGRAPH OF STRUVE'S BASE APPARATUS. Presented by the Pulkowa Observatory.

The apparatus here illustrated was designed by W. Struve and used by him in measuring seven bases of the principal triangulation of Russia, 1817–1855. It consists of four wrought iron bars enclosed in wooden cases, supported near the ends on trestles. The chief peculiarity of the bars is the use of spring contact levers. The temperature was measured directly by thermometers whose bulbs rested in cavities in the bar.

Struve estimated the mean probable error of his bases as 1 in 1,250,000.

Each iron bar is 2 toises (nearly 4 m.) long, and has a square section of 3·4 cm. side. It terminates at one end in a small steel cylinder, having a slightly convex outer face. To the other end is pivoted a lever with unequal arms. On the lower arm is a polished hemisphere, pushed outwards from the bar by a weak spring. The steel cylinder of the adjacent bar makes contact with this hemisphere, and forces the longer arm of the lever to traverse a vertical graduated scale. Any slight variation in length of the bar is correspondingly magnified by the lever on the scale, and can be accurately measured.

Two mercury thermometers are placed with their bulbs in recesses in each bar, and serve to measure the temperature directly. There is also a spirit level attached to determine the inclination of the bar.

(*See* " Encyclopædia Britannica," XI Edition, Article " Geodesy.")
Inv. 1876–1211.

64. COLBY'S COMPENSATION BARS. Presented by the Ordnance Survey. Plate I, Fig. 2, p. 15.

This apparatus was designed by Major-General Colby, R.E., in order to eliminate the errors in measuring bases caused by the impossibility of estimating

accurately the temperature of the measuring bars at the time of observation. The device of Colby consists in so connecting two bars, one of brass and the other of iron, that two reference marks on metal tongues attached to them remain at an invariable distance apart whatever the temperature.

Two bases have been measured with this apparatus, one in the North of Ireland in 1827–28, and the other on Salisbury Plain in 1849. Ten bases have been measured with similar apparatus in India.

In this apparatus two bars, one of brass and the other of iron, each 10 ft. 1·5 in. long, 0·5 in. broad and 1·5 in. deep at a certain temperature, are placed 1·125 in. apart and firmly connected at their centres by two small transverse steel cylinders, nearly in contact. Near each extremity of the double-bar is a metal tongue, 6·2 in. long, which is connected to each bar by pivots so as to permit expansion, but no other movement of the bars. On a silver plug at the extremity of each tongue is engraved a dot—the compensation point. Since the lengths of the tongue between the dot and either bar is proportional to the coefficient of expansion of that bar, no joint expansion of the bars due to temperature changes will affect the position of the dot. Consequently the dots are 10 ft. apart at all temperatures.

The compound bar is placed in a deal box, and is kept from moving lengthwise by a brass stay fixed firmly to the bottom of the box at the centre and projecting upwards between the two small steel cylinders connecting the bars. A long level is fixed to the top of the brass bar and read through a glass covered opening in the top of the box. The tongues carrying the compensation points project beyond the box, but are carefully protected.

In measuring, the boxes are supported at their quarter and three-quarter points on stands which permit lateral and longitudinal motion. The dots on two adjacent bars are brought to the precise distance of 6 in. apart by means of a compensation microscope. This latter is formed by uniting two microscopes by parallel bars of iron and brass in such a manner that the distance between their outer foci remains exactly 6 in., whatever the temperature. The whole apparatus consists of six bars and seven microscopes, of which two bars and three microscopes are exhibited. The rate of measurement with this apparatus was six bars per hour on the Lough Foyle base.

(*See* Ordnance Survey "Report on Measurement of Lough Foyle Base," pp. 163, 164.) Inv. 1876–1201, S.M. 261.

65. JÄDERIN BASE MEASURING APPARATUS. Presented by the Survey of Egypt.

This apparatus for measuring geodetic bases is of the type first employed by Jäderin in Sweden in 1885, and was used in Egypt for determining second order bases from 1901 to 1907. In Jäderin's system, the massive rigid base-bars hitherto employed were replaced by light metallic wires or tapes freely suspended under a constant tension. The saving in labour and time thus effected easily outweighs the slight loss in accuracy sustained. Independent measurements of each section of the base are made with two wires of different metallic structure, and the effect of temperature variations is thus calculated.

The apparatus exhibited comprises two tripods and two pairs of wires, 25 and 50 metres long respectively, each pair consisting of one brass and one steel wire. The tripods are provided with steel observing pins mounted upon double ball and socket joints, which permit slight displacements of the pins when the tripods are fixed. The wires are nickel-plated, and are provided at each end with decimetre scales, graduated in millimetres. The centimetre divisions of these scales are numbered from 5 to 15, and the length of the wire between the "10" division at each end is the characteristic length. The wires terminate beyond the scales in loops, to which are attached the flexible cords carrying the straining weights. The tension may be applied by hand, and measured by a spring balance, or by attaching weights to the cords. The cord at each end passes over a pulley mounted on a straining rod or trestle, which serves to take the end strain and to adjust the scale of the wire during the actual measurement into close proximity to the side of the observing pin. Observations of the positions of each pin with respect to the corresponding scale are simultaneously recorded. Several dual observations are made with each wire of a pair, the wire being slightly displaced for each observation.

Previous to the actual measurement of any bay, the pins of the tripods marking the ends of that bay are carefully aligned and their heights determined by a transit theodolite and level.

With this apparatus, various bases in Egypt were measured with probable errors between 1 in 200,000 and 1 in 1,000,000 at a speed of about 1,000 metres

per day. The higher degree of accuracy was consistently attained when the "constants" of the wires were known properly, and the observing parties had gained experience in correctly applying the tension to the wires. Recently the invention of "invar" has obviated the employment of two wires in the Jäderin system, and with improved straining mechanism, it is now possible to measure bases with Jäderin "invar" wires or tapes with an accuracy high enough for first order triangulation purposes.

(*See* "Geodätische Längenmessung mit Stahlbänden und Metalldiäpten," E. Jäderin, Stockholm, 1885; also U.S. C & G. S. Report, 1893, Part II, Appendix 5.) Inv. 1913–560.

66. PHOTOGRAPHS OF SECONDARY (STEEL) BASE-APPARATUS. Presented by the U.S. Coast and Geodetic Survey.

These three photographs illustrate a base-measuring apparatus constructed in July, 1891, and employed by the U.S. Coast and Geodetic Survey Department in measuring the Holton (Indiana) Base in 1891, the Salina (Kansas) Base in 1896, and the Versailles (Missouri) Base in 1897 in connection with the Transcontinental (Primary) Triangulation of the 39th Parallel of Latitude.

The apparatus consists of two precisely similar base-bars, known as the U.S. C. & G. S. Nos. 13 and 14 measuring bars. Each bar is of the contact-slide metallic-thermometer type, and is 5 m. long at a certain temperature. The actual measuring unit is a steel rod 8 mm. in diam., terminating at one end in an agate plane, and at the other in a contact-slide which itself ends in an agate knife-edge. The slide is connected to the rod by a spring, and has a mark engraved upon it corresponding to a mark engraved upon the rod, so that when these two marks coincide, the knife-edge and plane terminal points are the correct distance apart. Two zinc tubes, 9·5 mm. in diam., are soldered one to each end of the steel rod, their other ends being free to expand or contract relatively to this rod. The relative expansion is measured by means of a vernier on each zinc tube moving over a scale fixed to the steel rod, and the compound rod thus formed enables the mean temperature to be determined.

The compound measuring rod rests upon rollers in a rectangular wooden case, which itself rests upon tripods during the measurement and is provided at its rear end with a telescope for aligning the bar. When the forward bar has been aligned and adjusted as a whole on its trestles to within a small distance of the preceding bar, its measuring rod is slowly drawn backwards upon the rollers by a milled screw at its rear end, until the contact-slide touches the agate plane of the preceding bar and is forced gently over the steel rod until the two engraved lines coincide. During this motion, the wooden case remains stationary upon its trestles, and the only pressure upon the rear bar is that due to the spring of the contact-slide, which is quite powerless to disturb the bar.

Each bar is provided with a mercurial thermometer for use when comparing it with the standard bar.

The average rate of measurement with this apparatus on the Holton Base was 155 m. per hr., with a probable error of about 1 in 1,500,000.

(*See* Special Publication No. 4, U.S. C. & G. S. Department).

Inv. 1914–388.

67. PHOTOGRAPHS OF EIMBECK'S DUPLEX BASE APPARATUS. Presented by the U.S. Coast and Geodetic Survey.

These three photographs illustrate a bimetallic contact-slide apparatus designed by W. Eimbeck, and used by the U.S. Coast and Geodetic Survey Department in measuring the Salt Lake Base (Utah) in 1896 in connection with the Transcontinental Triangulation of the 39th Parallel of Latitude. It consists of two similar bars, each 5 m. long, known as U.S. C. & G. S. Nos. 15 and 16 duplex bars. The rate of measuring with this apparatus in Utah was about 250 m. per hr., with a probable error of 1 in 5,000,000.

Each bar consists of two measuring units of precisely similar construction, one of steel and one of brass, each 5 m. long, and weighs complete 118 lb. The measuring units are made of tubing of $\frac{3}{4}$ in. diam., each having a thickness of wall corresponding to the conductivity and specific heat of the material of which it is made, so that under changing conditions each tube shall keep the same temperature as the other one. The two measuring tubes are carried on rollers in a brass protecting casing, which turns on its longitudinal axis in an outer brass protecting casing which remains stationary. The inner casing is rotated 180° from time to time to equalize temperature distribution. The two measuring units are entirely disconnected, and contact is always made brass to brass and steel to steel; hence two independent measurements of the base are obtained, their difference

determining the average temperature during the measuring, so that each can be corrected accordingly. To overcome the difficulty due to one rod gradually gaining on the other, owing to the different coefficients of expansion of brass and steel, each measuring unit is provided with vernier scales, and the brass bar is occasionally readjusted by an amount thus measured and allowed for in the final calculations.

Telescopes are affixed to each base-bar for aligning, whilst the tripods are provided with special heads for quick and slow adjustment in the horizontal and vertical planes. The contact slide is similar to the one described in connection with the Secondary Base-Apparatus.

(*See* Appendix II, Report for 1897, and Special Publication, No. 4. U.S.. C. & G. S. Department.) Inv. 1914–389.

68. PHOTOGRAPHS OF TAPE-STRETCHING APPARATUS. Presented by the U.S. Coast and Geodetic Survey.

These three photographs illustrate a form of tape-stretching apparatus which is an improvement upon the one used by the U.S. Coast and Geodetic Survey in measuring the Stanton Base, Texas, in 1908–09.

It consists of an iron tube 1·35 m. long and 32 mm. diam., along which is movable a short collar fitted with a frame to carry the spring balance, and a weight to counterpoise it. The position of the sliding collar is easily adjusted by means of a friction lever device. The bottom of the tube ends in a round conical point, which permits it to rotate about its axis, thus allowing the tension to put the balance into alignment with the tape. A short iron projection near the bottom of the tube is used for forcing the latter into the ground by means of the foot.

The total weight of the stretcher is 11½ lb.

The rear end of the tape is attached by a strap to a simple wooden staff fitted with a metal shoe, as shown in the left-hand photograph.

The tension normally applied by this means to an "invar" tape for primary base-measurement is, in the United States, 15 kg.

(*See* U.S. C. & G. S. Report, 1910, Appendix 4.)

Inv. 1914–390.

69. "INVAR" MEASURING TAPE. Made by J. H. Agar Bough.

The name "invar" has been given to a nickel-steel alloy containing from 35 per cent. to 36 per cent. nickel, discovered by Dr. C. E. Guillaume in 1896, owing to its low coefficient of expansion for temperature, which is not greater than $1{\cdot}0 \times 10^{-6}$ per °C. The application of this alloy to geodesy arises from the difficulty of ascertaining the exact mean temperature of a metal measuring unit, and consequently the precise length of the unit at the time of measurement. As the effect of an error of this type is directly proportional to the expansibility of the metal, the importance of a low coefficient of expansion is obvious.

The use of "invar" wires or tapes, suspended under a constant tension of about 10 kg. according to Jäderin's method, is now almost universal in measuring bases for triangulation of the first or second order.

The tape exhibited is just over 100 ft. long, and has scales divided to read two-hundredths of a foot at each end. According to the National Physical Laboratory certificate of examination, the length between its zero marks at each end is 100·001 ft. at 58·5° F., under a tension of 10 kg., with an accuracy of 1 in 100,000. The width of the tape is 5 mm. and its thickness 0·5 mm. It is wound upon an aluminium drum of 16 in. diam., which can rotate upon its pivot as the reel is unwound.

(*See* "Les nouveaux appareils pour la mesure rapide des bases géodésiques." Guillaume et Bénoit. Paris, 1916.) Inv. 1912–245.

70. PHOTOGRAPHS OF BASE MEASUREMENT WITH "INVAR" WIRES. Presented by Major G. G. Waterhouse, R.E.

These four photographs of the measurement of the Narguta base in 1912, during the survey of Northern Nigeria, illustrate the general process of using flexible wires, suspended according to Jäderin's method, and the superiority of such apparatus over rigid rods in difficult country. In this case a river, the Delimi, having fairly steep banks, was successfully negotiated without any special preparation of the ground. Two of the photographs illustrate the approach to the Delimi and its crossing, a third shows the crossing of a deep irrigation channel, and the fourth shows the completion of a section of the base, the terminal point being marked by a ground pin. Inv. 1920–655.

INDIRECT MEASUREMENT OF DISTANCE.

RANGEFINDING.

Problems involving the determination of the distance of an inaccessible object have aroused great interest from very early days, particularly among military surveyors. Thales of Miletus, in the 6th century B.C., already applied his knowledge of geometry to determine the distances of ships at sea from the shore, and Hero of Alexandria, in his treatize on "the dioptra," written in the 1st century A.D., shows how to apply this instrument to solve problems of rangefinding. The surveyors of the Middle Ages and Renaissance periods constantly discuss similar problems, and show how to solve them by triangulating from a short, measured base. The subtense method of rangefinding, in which the base is situated on the distant object, has long been employed for astronomical purposes, and is often still used in marine surveying, where the object ranged upon provides a known length, such as the ship's mast, which can serve as base (*see* Nos. 71 and 72). Generally, however, the tendency in land surveying is to employ the ordinary system of triangulating from a "home" base, with the restrictions that this base shall be very short compared with the distance to the object ranged upon, and very nearly perpendicular to the direction of that object. Under these conditions, a very simple formula connects the required range and the angle of convergence of the rays from either end of the base to the distant object; this angle can be micrometrically varied to suit the range, and the latter read off directly on a special scale connected with the mechanism controlling the angular variation. By this means, the necessary rapidity of ranging upon moving objects is attained. Many modern rangefinders, such as the Labbez and Gautier Telemeters and the G.S. Mekometer (*see* Nos. 73, 75 and 76), require either two observers or separate measurements from each end of the base, which is usually fairly long—about 50–100 ft. —but the more precise types have a base fixed in the instrument itself, and are operated by a single observer, who sees simultaneously two views of the distant object obtained by rays from each end of the base. One of the earliest rangefinders of this latter type was invented in 1775 by an optician named Magellan, and had an adjustable base in the instrument itself. In a rangefinder patented in 1858 by General Clark, two views of the object were reflected from mirrors situated one at each end of the fixed base tube, into a central telescope, so that the observer saw two images of the object, separated by a short lateral distance; the range of the object could be rapidly calculated by measuring this distance micrometrically.

In 1860 Adie patented a short, constant-base rangefinder (*see* No. 77) in which the two images of the distant object were made to "coincide" in the central telescope field, by means of a rotation of the inner tube carrying one end reflector system within the outer tube containing the other end system. Soon after this date, Steinheil, in Germany, and Tavernier, in France, brought out rangefinders in which the "coincidence" of the images was effected by rotating one of the end reflectors. The employment of pentagonal prisms, now generally used, as end reflectors instead of plane mirrors or triangular prisms appears to have been first made by Colonel Goulier about 1864.

In 1888 Messrs. Barr and Stroud invented their well-known short-base coincidence rangefinder (*see* No. 78), in which the coincidence

was effected by the lateral movement of a deflecting prism interposed between the central telescope and one of the fixed end reflectors. The same firm have since introduced many improvements in their original type of rangefinder, whilst preserving the deflecting prism as an essential feature.

A different principle is involved in the stereoscopic type of rangefinder, in which the capacity of the human eyes to " converge " upon a distant object is utilized to measure its distance. In such an instrument the muscular effort of the eyes during convergence is a delicate measure of the required range, and the optical systems employed merely enhance the range within which this effort can be accurately distinguished. The foundations of stereoscopic measurement were laid by Wheatstone in 1832 and by Helmholz in 1855–58, but the first rangefinder utilizing this principle was conceived by De Grousilliers in 1893 and developed by Messrs. Zeiss in the subsequent years. Stereoscopic rangefinders, whilst very accurate and rapidly manipulated in the hands of a skilled observer, necessitate a power of stereoscopic perception not possessed by everybody. A rangefinder of this type, devised by G. Forbes in 1901 for infantry use, is exhibited in the Collection (No. 80).

71. STADIOMETER. Made by W. Heath. Presented by the Admiralty.

This instrument was designed by Capt. G. H. Blakey, R.N. for determining the distance of a ship on the assumption that the height of its mast is known, and that the mast is perpendicular to the direction of the ship from the observer. It is merely a telescopic sighting tube having a pin-hole aperture and pairs of parallel wires set at known intervals apart near the object end of the tube. The distance of these wires from the aperture is given by the graduated scales on the telescopic tube.

In using the instrument, the mast of the distant ship is viewed and the sighting tube telescoped until the mast lies exactly between a pair of wires. On reading the length of the tube, *i.e.* from aperture to wires, the range of the mast will be in the same ratio to this length as the mast is to the interval between the wires. As these last two lengths are known, the range is readily calculated, or can be obtained directly from the tables supplied with the instrument. Two mutually perpendicular pairs of parallel wires are fitted in the instrument exhibited, at intervals of one tenth and one twentieth of a foot respectively. A table corresponding to the former interval for lengths of masts between 100 and 200 ft., and all possible lengths of sighting tube is printed on the tube and gives the corresponding ranges in yards. For the smaller interval, these ranges are of course to be doubled.

Measurements of distance by this apparatus can only be very approximate owing to the absence of magnification, uncertainty as regards the length of the mast and its inclination to the line of sight, etc. Inv. 1876–1209.

72. STUART'S DISTANCE METER. Presented by T. H. Court, Esq.

Assuming that the length of a distant ship's mast is known, its range can be found by this instrument, which was designed in 1895 for use at sea. Two images of the mast are seen in the field of the telescope, one formed by light rays traversing a fixed prism of constant angle, and the other by rays traversing a movable prism of varying angle. These images are made to approach each other until the lower limit of one is level with the upper limit of the other by sliding the movable prism, when the position of an index attached to this permits the range to be read.

The movable prism consists of a thin piece of glass, ground concave on both faces, and is attached to a slide worked by a tangent screw. It thus forms a prism of varying angle in front of one half of the telescope, the other half being occupied by the fixed constant angle prism.

Ranges up to 3 miles can be read to the nearest tenth of a mile.

(*See* British Patent Specification, No. 23834, 1895.) Inv. 1915–399.

73. LABBEZ TELEMETER.

This is a pocket rangefinder suitable for military reconnaissance. To determine ranges up to 3,000 m. two observations are made with it, one from each end of a 30 m. base, which is set off approximately at right angles to the direction of the object.

The instrument consists of a short metal tube having a pin-hole sight at one end and a rectangular window in one side. Opposite this window within the tube are two small plane mirrors inclined at an angle of 45° to each other. Both mirrors can be rotated slightly. The observer views the object A whose range is required directly through the pin-hole sight, and rotates one mirror until he sees, after double reflection, the image of an object B whose direction is nearly at right angles to A's. He measures off the base in the direction of B, and again views A directly. By rotating the second mirror he once more gets a doubly reflected image of B. This latter rotation is effected by turning a milled drum in the eye end of the instrument, and the position of this drum when B is again sighted is a measure of the range of A. The drum is calibrated to give this range immediately.

A thin cord of the base length is supplied with the instrument.

(*See* " Fieldwork and Instruments," 1900, pp. 236–239, by A. T. Walmisley.)

Inv. 1920–66.

74. THREE-PRISM TELEMETER. Presented by T. H. Court, Esq.

This instrument is used to measure ranges in the ordinary manner, by solving a very acute right-angled triangle. The angle subtended at the distant point is constant, whilst the base is variable, and is measured by pacing.

Three reflecting right-angled prisms are mounted by hinged joints near the objective of a small telescope, so that any one of the three can be set to reflect rays axially along the telescope from directions at 90°, 88° 51′ 15″ and 74° 53′ 15″ respectively. The first prism is used to set off the base at right angles to the direction of the distant object. The observer paces in the line of the base until, using one of the other two prisms, he again sees the object by reflection. For both observations the telescope is directed to view another distant point at right angles to the target, *i.e.* in the direction of the base. The number of paces taken between the two observations, multiplied by a constant depending upon the length of pace and the reflecting angle of the second prism used, gives the required range. The constant is determined experimentally. Inv. 1911–151.

75. GAUTIER'S POCKET TELEMETER. Made by Tavernier-Gravet, Paris.

This rangefinder was designed by Capt. Gautier, a French artillery officer, about 1865, and has been extensively used in the French army. Its main feature is a thin prism mounted in a ring at the object end of the sighting tube. By rotating the ring the deviation of rays in the plane of the distant object and the horizontal through the instrument can be varied continuously, and the ring calibrated correspondingly.

The sighting tube is about 5 in. long by 1′·5 in. diam. and has a protecting tube which can be fitted underneath to serve as a hand-grip when observations are being made. The sighting tube, in addition to the movable ring containing the prism, has a pair of plane mirrors having their faces inclined to each other at an angle of about 45°, and so inclined to the optical axis that rays incident through a window in the side of the tube in a direction nearly perpendicular to the axis, are doubly reflected at the mirrors into the line of the axis, and pass through a small telescope at the eye end of the tube. In the instrument shown, two such telescopes of different powers are fixed side by side. One of the mirrors can be slightly rotated so as to vary the angle of deviation of the reflected rays.

In using the instrument, the observer sets the range scale on the movable ring at " infinity " and the index of the movable mirror at the centre. He views the distant object by double reflection at the mirrors and looks directly through the tube and prism for a convenient aiming mark. If such a mark is not quite coincident with the image of the distant object, he rotates the mirror until coincidence occurs. Then the object and the aiming mark are in directions nearly perpendicular to each other. Next he paces out a convenient distance in the direction of the aiming mark and takes a second observation similar to the first, but this time effects the coincidence by means of the movable prism. He reads off the scale calibrated on this ring when coincidence is effected and multiplies the distance so read by the length of his base. The result is the range of the distant object. The movable ring is really calibrated to record the reciprocal of the angle of deviation caused by the prism, which is the same as the reciprocal of the angle subtended

by the base at the object. As this base has been made nearly perpendicular to the direction of the object, the product of its length and the reciprocal of the angle gives the range. Thus any convenient base length can be used subject to the condition that it subtends an angle of not more than 3° at the distant object.

(*See* " Notice sur le Télémètre de Poche," by A. Gautier, Paris.)

Inv. 1910–126.

76. MEKOMETER, GENERAL SERVICE PATTERN. Made and lent by T. Cooke and Sons, Ltd., York.

This standard rangefinding set is used by infantry units. It comprises two optical sighting instruments, known as the " Right Angle " and " Reading " instruments, and two reels of cord, each 25 yd. long, for setting off the base. The observer at one end of the base uses the " Right Angle " instrument to make the base line perpendicular to the line joining his position to the distant object, after which the other observer uses his " Reading " instrument to measure the angle between the base line and the direction of the object from his position.

The Right Angle instrument has two fixed vertical mirrors inclined to each other at an angle of 45°. The observer using this sees the target directly and the vane on the Reading instrument after double reflection at the two mirrors. He adjusts his position, keeping the base line fully extended, until the two images coincide.

The Reading instrument differs only in that one of its mirrors can be rotated, and the rotation recorded upon a graduated drum, so that the images of the target (viewed directly) and the vane of the Right Angle instrument (viewed by double reflection on the two mirrors) can be made to coincide. The graduated drum is calibrated to record the range directly.

(*See* " Handbook of the Mekometer.") Inv. 1914–293.

77. ADIE TELEMETER. Presented by the Admiralty.

This type of rangefinder was designed by P. Adie in 1860, and was extensively used by the Admiralty until superseded by the Barr and Stroud pattern. The example shown was used on H.M.S. " Triton " from 1885 to 1904 during the survey of the East Coast of England.

The rangefinder consists of two systems of lenses and right-angled reflecting prisms mounted in a 3-ft. metal tube of square section. Each system forms a " broken " telescope, the objectives being at each end of the tube, along which the rays, originally perpendicular to it, are deflected by right-angled prisms to the centre, where they are again reflected at right angles into the common central eye-piece. In this manner two images of a distant object whose direction is nearly perpendicular to the axis of the tube are obtained, one through each system. These images will be separated laterally by an interval which diminishes continuously as the range increases, but does not become zero until the object is at an infinite distance. If the objective lens and two prisms of one system are separately mounted and can be rotated with respect to the other system, the two images may be made to coincide by such a rotation, and the angle of rotation necessary will vary inversely as the range of the object. This angle can be measured and the range obtained by calculation, or a table of corresponding values. In the instrument exhibited such an arrangement is effected by mounting one object lens and its pair of reflecting prisms in a separate tube within the main tube containing the other set, and pivoted to this so that the rotation can be effected by a screw threaded in the outer tube with its end pressing against the inner. The angle of rotation is measured by a vernier on one tube and a scale on the other to the nearest second of arc, and the range read off on a table fixed to the outer leather protecting cover.

(*See* British Patent, 1860, No. 357 ; and 1863, No. 608.) Inv. 1909–139.

78. BARR AND STROUD INFANTRY RANGEFINDER. (Early Type.) Lent by Messrs. Barr & Stroud, Ltd.

This instrument was made in 1889, and is one of the first rangefinders constructed by Messrs. Barr & Stroud for use by infantry. It is a single-observation, coincidence instrument, with a fixed base of 80 cm., and measures ranges between 200 and 2,000 yd. with a percentage error directly proportional to the distance.

The instrument is optically equivalent to a pair of telescopes having a common central eye-piece and their axes in opposite directions along the base-line, at the ends of which are the two objective lenses. Two pencils of rays diverging from the distant object to each end of the instrument are reflected at right angles by mirrors so as to traverse the objectives and form two images at the centre, where

they are again reflected at right angles by a pair of mirrors, one of which is parallel to each end mirror. The two images are thus viewed in the focal plane of the right eyepiece of the instrument, and are separated laterally by a distance inversely proportional to the required range. Between the right objective lens and the central mirrors there is a small angled deflecting prism, which can move along the axis, and in so doing increases or decreases the amount of separation of the two images. In one position of the prism, corresponding to the distance of the object, the two images coincide. A scale attached to the prism moves with it and is graduated so as to give the range directly. This scale and its fixed index-line are viewed by the observer's left eye in a separate eyepiece, which also serves in conjunction with a field lens as a small telescope of large field for picking up the target.

In using the instrument the observer picks up the target with his left eye, turns the pinion actuating the deflecting prism with his right hand until the two images of the object in the right eyepiece coincide, and reads off the desired range with his left eye.

(*See* "The Modern Rangefinder," by Prof. F. J. Cheshire. "Theory of Modern Optical Instruments," Appendix on Rangefinders, by Gleichen. British Patent No. 9520–1888.) Inv. 1914–180.

79. BARR AND STROUD RANGEFINDER ON NAVAL MOUNTING. Lent by Messrs. Barr & Stroud, Ltd.

This instrument was used by Dr. Bruce in the Weddell Sea Antarctic expedition on the "Scotia," 1902–04, and afterwards by Capt. R. F. Scott, R.N., on the "Terra Nova" in the British Antarctic expedition 1910–13.

The rangefinder is of the F.A.2 type, base 4 ft. 6 in., mounted on a type N.M. naval mounting which permits the tube to be rotated in azimuth and altitude. Its optical system is functionally similar to that of the adjacent early infantry type, but special reflecting prisms replace the mirrors there employed. The two images formed in the central eyepiece are erect, and are separated by a fine horizontal line bisecting the field. Coincidence of these images is effected by moving a deflecting prism to which is attached a scale whose lateral motion is measured and indicates the required range as in the earlier instrument. The scale can be illuminated for night reading, when a cylindrical lens astigmatiser is put into action and serves to draw out the images of a luminous point into fine vertical streaks suitable for effecting coincidence. The instrument can be adjusted at a known range by "halving" and "coincidence" fittings, and will then read all ranges correctly.

The approximate uncertainty of measurement varies from 2 yd. in 1,000 to 200 in 10,000, the percentage error increasing directly with the range. The magnification of the main telescope system is 26 diam., its angular field of view 1° 20′ horizontally and 0° 40′ vertically. The finder telescope magnifies 2·5 diam. and has a 7° field of view.

(*See* "The Modern Rangefinder," by Prof. F. J. Cheshire. "Theory of Modern Optical Instruments," Appendix on Rangefinders, by Gleichen.) Inv. 1914–179.

80. FORBES' STEREOSCOPIC RANGEFINDER. Lent by Prof. G. Forbes, F.R.S.

Prof. Forbes designed this type of rangefinder in 1901, for use by infantry in measuring ranges up to 3,000 yd. The power of the eyes to "converge" to a varying degree upon objects at different distances, and to measure distances by the muscular effort so required, is limited normally to small distances of a few yards. Consequently, in this, as in all stereoscopic rangefinders, optical means are employed to bring the image of the object ranged upon within the limit of normal eye convergence. The use of an optical base, whose function is to increase the inter-ocular distance from 2·5 in. to 72 in., and a pair of binoculars of magnification 8 diam. enables the radius of stereoscopic vision to be increased 240 times.

In this instrument, the optical base consists of two pairs of doubly reflecting pentagonal prisms, mounted one at each end and two at inter-ocular distance apart in the centre of a metal tube, which is hinged in the centre so as to fold into two portions each 38 in. long. When in use these two portions are clamped to form a single tube with the end prisms 72 in. apart. The binoculars are fitted with their objectives opposite the centre prisms, there being windows in the tube opposite all the prisms. After double reflection at the end and centre prisms, an image of the distant object is formed in the focal plane of each objective of the binoculars, in which plane there is a glass plate carrying a photograph of a

balloon. The distance between the two balloon images is varied by a micrometer screw. If the observer combines these balloon images stereoscopically into one, and does the same with the images of the distant object, he can judge the apparent distances of the two images, and turn the screw until these distances coincide. The rotation of the screw thus serves as a measure of the required range, and this can be read off directly on a circular scale, attached to the screw and suitably graduated.

With practice, an observer having good stereoscopic vision can determine ranges with a rapidity and accuracy comparable with that of a coincidence rangefinder, and with the additional advantage for military purposes that the object need not be seen very distinctly. Inv. 1920–442.

TACHEOMETRY.

The method of tacheometry consists in obtaining, with only one " setting " of a theodolite specially adapted for rangefinding, the three polar co-ordinates—distance, azimuth and altitude—of every distant point which is visible and accessible from the observing station. Thus the positions of all such points with reference to the observing station as origin are fully determined, without any direct measurement of length, both rapidly and accurately enough for engineering, reconnaissance and topographical surveys.

By setting up a staff at the distant point, and taking the altitudes and azimuths of two points on it at a known distance apart, it is possible to use any ordinary theodolite for finding the required distance of the staff from the observing point. The calculation of this distance from the data is, however, somewhat laborious, so that a tacheometer is a theodolite fitted with special devices both for accurately estimating the small angles involved and for reducing the necessary calculations. Generally, the staff is set up in the vertical plane through the line joining the observing station to the distant point, and is set either vertically or perpendicularly to this line. The two points on the staff may be at a constant distance apart, or the angle subtended by these points at the observing station may be constant. In the former case the angle subtended varies, whilst in the latter case the length cut off upon the staff varies with the distance, and consequently in this case the staff is graduated. The angle-measuring device special to the tacheometer may take the form of a microscope mounted so as to make a fixed angle with the telescope, and rotate with it about a common transverse axis (*see* No. 83) ; or may consist of a special diaphragm fitted at the focal plane of the object glass of the telescope. This diaphragm contains two parallel lines—defined by metallic filaments, hairs, spider's web, or some similar device—and the angle subtended by the interval thus defined at the optical centre of the object glass is equal to the angle subtended by the known length on the staff at the same point. The interval at the diaphragm is accurately measured by a micrometer-screw—or is made constant—and the focal length of the object-glass being known, the distance of the staff from the object-glass can be easily expressed in terms of the three known quantities—diaphragm-interval, focal length, and staff-interval.

The tacheometric-diaphragm was first introduced into the Keplerian telescope by a young English astronomer named Gascoigne, in 1639. Gascoigne fitted into his telescope a movable micrometer diaphragm, made of metal threads whose distance apart could be calculated to 1/400th inch and varied by a micrometer screw, and used it for measuring astronomical and terrestrial distances. His device was not,

however, made known generally until 1667, and meanwhile a similar appliance had been invented and used on the continent for astronomical purposes. Hooke suggested the substitution of hairs for the metallic filaments in the diaphragm, and this was carried out in 1674 by Montanari, who used his instrument for terrestrial work. He used 12 to 15 hairs and a vertical staff of constant length. About a century elapsed, however, before the method became at all familiar to surveyors by the publication of a book on surveying by William Green, in 1778. Green described an instrument constructed by him and used for measuring distances on the same principle as the tacheometer, but called by Green a stadiometer. A similar contrivance had been employed by James Watt in surveys for the Tarbert and Crinan Canals, in 1771. About the same period Brander employed a diaphragm constructed of lines engraved on glass by means of a diamond, and applied it specially to the sight rule of his plane-table. These methods were rarely used, however, until Porro, in 1823, designed his " anallatic" telescope, which reduced the calculations hitherto necessary for tacheometry. Many instruments were constructed which embodied Porro's principle of the anallatic lens (*see* No. 81), the most famous being the " Cleps " tacheometer, made in 1867. Since that time, several mechanical appliances have been designed with the object of reducing calculation to a minimum, but many surveyors still prefer to use an ordinary theodolite whose telescope is fitted with " stadia " lines, in conjunction with a graduated staff for tacheometric purposes, and to perform the necessary calculations with the aid of tables.

81. TACHEOMETER. Made by Troughton & Simms.

A Porro " anallatic " lens is inserted between the objective and eye lenses of this instrument and its horizontal and vertical circles are divided centesimally. It is used in conjunction with a graduated tacheometric staff, upon which the interval subtended between the fixed cross wire varies directly as the distance of the staff from the transverse axis of the instrument, which is itself vertically above the observing station point.

In the case of an ordinary telescope, the interval subtended by the fixed diaphragm wires upon the staff varies directly with the distance of the staff from the first principal focus of the object lens. Thus, to get the distance from the station point, a constant equal to the distance between this focus and the station point, or the transverse axis of the instrument, must be added in every case. This is unnecessary when an anallatic lens is used, for this lens is so placed that the transverse axis is the conjugate point of its first principal focus with respect to the objective lens, and is thus the first principal focus of the combination of the two lenses.

In the diaphragm of this instrument there are five horizontal wires and one vertical wire, so that a pair of cross wires may be chosen to suit the magnitude of the distance measured.

The focal length of the objective lens is 9·5 in., that of the anallatic lens being 6 in. The eye-piece is of the Ramsden type, and can be traversed vertically through a small distance relative to the telescope. The anallatic lens is fitted in a separate tube inside the telescope tube carrying the objective lens, and can be adjusted by a rack and pinion arrangement actuated by a special key. The divided circles are 4 in. diameter and are read by verniers to centesimal minutes. Inv. 1890–55.

82. GENTILLI'S TACHEOMETER. Made by Stärke & Kammerer, Vienna.

To convert a theodolite into a tacheometer for measuring distances, many devices have been proposed which permit the telescope, when directed upon a graduated staff, to be displaced through a constant small angle, whose limits are determined by two mechanical stops. The distance so measured on the staff will vary directly as the horizontal distance of the staff from the observing station

and inversely as the square of the cosine of the altitude angle. As the latter is known, the former can be calculated by using special tables. In the tacheometer invented about 1868 by A. Gentilli, the Austrian engineer, a rigid vertical arm can be clamped to the transverse axis of the telescope in any position. The lower end of this arm can only move a short distance, being limited by two mechanical stops. Consequently the vertical angle through which the telescope can move when clamped to the arm is likewise limited.

The instrument in other respects is like an ordinary theodolite of the type made by Stärke about this period. It has a 5-in. horizontal circle and a 3·5-in. vertical quadrant, both reading by vernier and reading microscope to 30″ and having the usual clamps and tangent screws. The telescope has an objective lens of 12 in. focal length and 1·5 in. aperture. The instrument has four levelling screws, two small spirit levels mutually perpendicular on the horizontal circle, and a more sensitive one on the telescope. Inv. 1876–1205.

83. ECKHOLD'S OMNIMETER.

An early example of a theodolite modified to enable distances to be measured with it simultaneously with azimuth and altitude angles is here represented in the "Omnimeter," invented by C. A. C. Eckhold in 1868. This instrument is used in conjunction with a special tacheometric staff having a fixed interval, usually 10 ft., marked upon it. A microscope, rigidly attached with its axis perpendicular to that of the observing telescope, rotating with this telescope about a common transverse axis, measures upon a scale fixed horizontally upon the upper plate of the theodolite the distance traversed when the observing telescope is rotated from the upper mark to the lower mark of the staff. As this staff is always set up vertically, its horizontal distance from the centre of the instrument is inversely proportional to the distance traversed on the scale.

The microscope scale is mounted parallel to the telescope at a distance of exactly 6 in. below the transverse axis. It is 4 in. long and is graduated to read 0·02 in. directly, whilst it can be moved on the plate, parallel to its own length, through a small interval by means of a micrometer screw with a graduated drum, which measures 0·002 of each division of the scale. In this manner the ultimate graduation of the scale corresponds to 4×10^{-5} in. so that, if n such divisions are traversed when the theodolite rotates from the upper to the lower mark of the staff, the distance of this staff from the instrument will be $15 \times 10^5 \div n$ ft. In other respects the instrument is similar to an ordinary transit repeating theodolite. It has 5-in. vertical and horizontal circles reading by vernier to single minutes. The focal length of the telescope is 11 in., and its aperture 1·25 in. It is fitted with a Ramsden eyepiece. Slow-motion tangent screws are provided for each circle, and the usual spirit-levels on the plate and telescope.

A diagonal eyepiece is fitted to the microscope for convenience in taking steep sights. Inv. 1900–90.

84. PHOTOGRAPHS OF JEFFCOTT DIRECT-READING TACHEOMETER. Made and lent by Messrs. Cooke, Troughton & Simms, Ltd.

Ordinary tacheometers are designed for horizontal sights, and the readings have to be corrected by computation if the sight is inclined, whilst a further calculation is necessary to determine the difference in height between the observed and observing stations. Many devices have been introduced in the design of tacheometers with the object of rendering such calculations unnecessary, and enabling the distance and altitude to be read off directly, whether the line of sight is horizontal or inclined. The tacheometer illustrated embodies Prof. H. H. Jeffcott's arrangement for rendering the readings independent of the inclination, by varying the diaphragm-interval proportionally with the inclination. A similar arrangement of varying diaphragm-interval enables the height also to be obtained by reading the staff-interval intercepted.

The diaphragm has one fixed and two movable horizontal platinum-iridium pointers, the former for collimation and the latter to limit the intervals for height and distance readings respectively; the distance pointer is on the same side as the collimation pointer, and the height pointer on the opposite side. Each movable pointer is fixed on the end of a pivoted lever, of which the other end is pressed against a suitably shaped cam, which is rotated by the movement in inclination of the telescope, so that the distance of either movable pointer from the fixed one is suitably varied to make the interval intercepted upon the distant staff exactly one-hundredth of the range and one-tenth of the height respectively. The cams are made to suit elevations and depressions up to 30°, and are mounted inside a protecting case at one end of the transit axis of the telescope.

The instrument in other respects resembles the ordinary tacheometric theodolite. It has a 5-in. horizontal circle, graduated on silver to 20 minutes and read by two verniers; one coarse vernier for ordinary use reads to 1 minute whilst the other, reading to 20 seconds, is only used in adjusting or testing the instrument. No vertical circle is supplied, unless specially desired. The telescope is provided with an anallatic lens, an objective of 1·65 in. aperture, and a screw-focussing, inverting eyepiece of power 18. The eyepiece is mounted in a movable slide for reading at extreme angles. Three bubble-levels are provided, one on the cover-plate, another above the telescope, and the third on the control arm of the cams; this last is particularly sensitive, having a bubble shift of 2 mm. per 15–20 seconds of elevation.

(*See* Brit. Patent Spec. No. 18721 of 1912. Transactions of the Institution of Civil Engineers of Ireland, Jan. 6th 1915.) Inv. 1925–7

85. TACHEOMETRIC STAFF. Made by Troughton & Simms.

This is a 4-metre wooden staff, graduated in centimetres and used in conjunction with the tacheometer, Cat. No. 81. It is inextensible, and does not materially differ from a levelling rod.

The graduation marks are black bands, 1 cm. wide, at intervals of 1 cm. Those corresponding to metres and decimetres extend right across the face, the rest only half across. The metres are numbered by large red numbers and the letter M, the decimetres by smaller black numbers. The half-decimetre points are marked by small black arrows.

The rod has a rectangular section, 3 in. wide by 1¼ in. deep, and the face is slightly sunk below the edges to prevent abrasion of the graduations.

Inv. 1890–55.

MEASUREMENT OF ALTITUDE.

The task of determining the relative altitudes of two places was one of fundamental importance in the earliest days of civilization. It arose primarily in connection with the vast irrigation projects of which traces still remain, but was also important in architectural and military work. For the solution of this problem we find both direct and indirect methods employed in the earliest times, as in our own day. Where both the places were readily accessible, the direct method of levelling was customary; where only one of the places could easily be occupied recourse was had to indirect or trigonometrical methods, which involved the measurement of the distance of the second place from the first, and the determination of the angle of elevation of one above the other. Thus Vitruvius, in his treatise on architecture, refers to the employment of the "chorobates"—a combined plummet and water-level—for setting out aqueducts, whilst Hero of Alexandria, in his work on the "dioptra," describes how this instrument could be used as a water-level for directly measuring altitudes and also as a sighting instrument for their indirect determination by angular measurements. As early as the 6th century B.C., Thales of Miletus is reported to have calculated the heights of mountains by measuring the lengths of shadows cast by them and comparing these with the shadow cast at the same time by a vertical rod of known height.

For some 2,000 years little change took place in the classical methods of altitude measurement, except that instruments for angular measurement were provided with graduated scales which facilitated the necessary calculations. In the 16th and 17th centuries, the normal surveying instrument was adapted to the measurement of angles in any plane, and could be as readily employed for measuring altitude angles as for determining horizontal ones. Occasionally at this period we find the sight-rule or diopter provided with a movable vane on the

foresight to facilitate altitude measurements, whilst in other instruments the altitude quadrant could be attached to or detached from the remainder of the instrument, which was specially arranged for measurements in horizontal planes only. The period is characterized by the use of indirect methods of measurement rather than the more precise, but more laborious, direct methods, such as levelling. In the latter part of the 17th century, however, when large aqueducts and canals were constructed in France, the necessity for more precise determinations of relative altitudes led to the design of elaborate levels provided with telescopes for sighting over large distances. The line of sight in these instruments was set horizontal by means of a plummet, of which the heavy telescope itself formed a portion of the weight (*see* No. 88). Levels of this " pendulum " type were constructed by Picard, Huygens and others. De la Hire, on the other hand, devised an elaborate water-level for use in such work.

In 1661 M. Thévenot described an appliance, the air or bubble-level, destined to revolutionize the construction of levelling instruments. This invention remained in obscurity for many years, owing principally to the difficulty of manufacture of accurate bubble-tubes. In 1702, however, A. M. Mallet, in his " Géometrie pratique," describes several air-levels, or spirit-levels as they are now called, and his book shows that in France, at any rate, the new appliance was gaining ground over the cumbersome plummet and water-levels. In the 18th century, it rapidly superseded these latter, and the bubble-tube became an essential adjunct to the telescope of the theodolite, which rendered that instrument capable of acting at will as a pure level, or of measuring altitude angles for indirect levelling. It was not until the beginning of the 19th century that surveying instruments designed purely to perform the functions of a level, but not those of a theodolite, came into general use, principally in canal and railway engineering surveys. Such instruments had rarely a divided circle, but were usually provided with a compass for measuring azimuth angles. They had very powerful telescopes, specially designed for taking short sights, and particularly sensitive bubble-tubes. Many improvements in the design of such levels have been made during the 19th and 20th centuries, with the view of ensuring greater accuracy and power without increasing their size, and of facilitating the necessary instrumental adjustments. Most modern levels are provided with tacheometric or stadia diaphragms in their telescopes which permit them to measure distances at the same time as the altitudes are read off.

The earlier staves used with direct levelling instruments were provided with movable sight-vanes, the position of which on the graduated rod could only be read by the staff-bearer (*see* No. 122). With the increasing power of telescopes, it became possible for the observer to read the graduated rod distinctly, and the movable vane became superfluous.

For trigonometrical levelling, which is more rapid but less accurate than direct levelling, the modern theodolite with its divided vertical circle and bubble-tubes is well adapted. Where still less accuracy is sufficient, and where other methods of altitude determination are impracticable, heights can be approximately obtained by means of barometers and hypsometers, the action of which depends upon the diminution of atmospheric pressure with increasing altitude.

In 1648, five years after the invention of the barometer by Torricelli, this instrument was employed by Pascal in the Puy de Dome area to

investigate the diminution of atmospheric pressure as the altitude increased. The exact law of variation was not properly established, however, for another 150 years. Gay-Lussac and Fortin devised important modifications of the mercury-barometer to adapt it specially to the determination of altitudes, but the invention of the aneroid type of barometer by Vidie in 1847 provided a much more portable instrument for the approximate measurement of heights.

The hypsometer, or boiling-point thermometer, which depends for its action on the lowering of the boiling-point temperature with diminishing atmospheric pressure and therefore with increasing altitude, was first devised by Wollaston in 1817 (*see* No. 131). Modified forms are often employed to supplement aneroid readings in modern exploratory surveys of mountainous regions.

PLUMMET LEVELS AND CLINOMETERS.

86. PHOTOGRAPH OF TWO ANCIENT EGYPTIAN LEVELS. Presented by Captain H. G. Lyons, F.R.S.

The original levels, which are of the A-shaped plummet type, are exhibited in the Cairo Museum and are of considerable antiquity. Such levels were used by builders and engineers of all the early civilizations and have survived in use to the present date without fundamental modification.

Each level consists of a wooden frame in the shape of an isosceles triangle, having its sides equally prolonged beyond the base. The ends of the legs are cut parallel to the cross piece, so that the frame may rest upon a flat surface. A plummet is suspended from the apex of the frame, and its cord passes over the front of the cross piece, in the middle of which is engraved a vertical mark. If the cord lies along this mark when the plummet hangs freely, the surface on which the level rests is horizontal.

Hieroglyphics are engraved in the face of the lower level. Inv. 1914–219.

87. INSTRUMENT FOR ASCERTAINING HEIGHTS. Presented by T. H. Court, Esq.

This consists of an isosceles, right-angled metal triangle which can be freely suspended by means of two brass pins so that its two equal sides are vertical and horizontal respectively. All objects in the prolongation of its third side will then be at a horizontal distance from the instrument equal to their height above it. The former distance can be measured, and the height thus ascertained. The hypotenuse of the metal triangle has a pair of sights which enable objects in its line to be viewed.

When using the instrument, the observer takes up a position from which he can sight the object whose height is required, the instrument being freely suspended. He then measures his horizontal distance from a point vertically beneath the object. This distance is equal to the height of the object above the eye-level of the observer.

When not in use, the instrument fits in the wooden case exhibited with it.
Inv. 1917–39.

88. EARLY BALANCE LEVEL. Lent by T. H. Court, Esq. Plate II, Fig. 1, p. 38.

This is a level of a type much used for rough levelling during the 17th century, and probably dates from the latter half of that period. It consists of a heavy tube freely suspended from the top of a wooden case by a thread attached to its centre. The tube has a horizontal slit at one end, and a corresponding cross wire at the other; glass windows in the ends of the wooden case permit a free view along the sights. The instrument as a whole can be rotated in azimuth upon its stand.

When not in use, the sighting tube can be fixed by means of two screws passing through the bottom of the wooden case.

In this instrument, the centre of gravity of the suspended tube is very little, if any, below the line of sight. Hence the tube is very sensitive to disturbances, which is a source of trouble. Moreover, there is no easy method

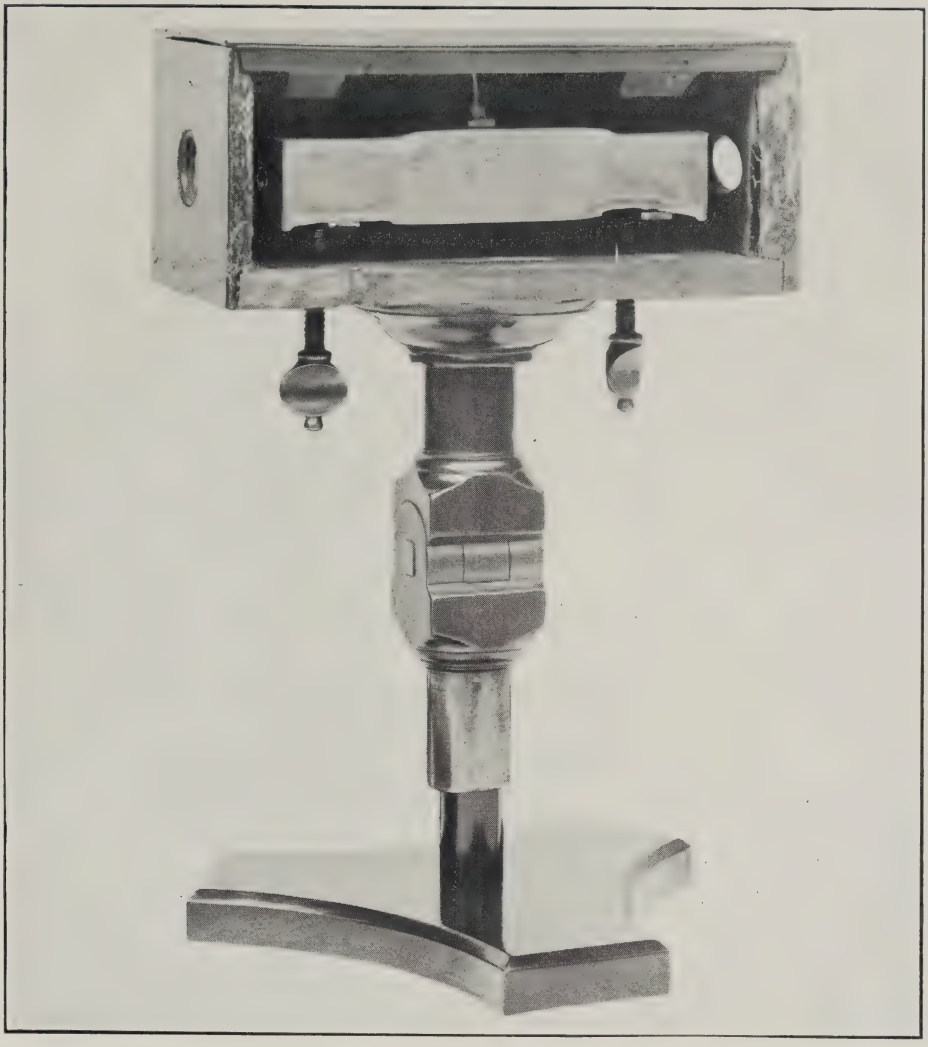

Fig. 1. Early Balance Level, p. 38.

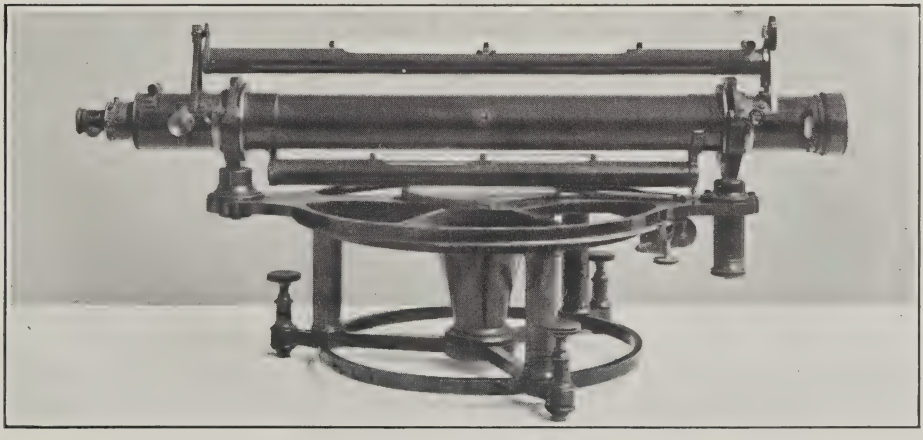

Fig. 2. Spirit Level, by Cary, p. 40.

of adjusting the line of sight to be truly horizontal. Owing to these defects, both of which were remedied in the more precise instruments on the " balance " principle designed by Huygens, this type of level is not very accurate.

The body of the tube is made of lead, the ends containing the sights being of brass. The wooden case is screwed into the top of a small column, provided with a brass socket at its other end. The socket serves to attach the level to its stand, which may be a tripod or simply a " stick " stand.

Inv. 1913–258, S.M. 951, L.S.

89. PLUMMET CLINOMETER.

This instrument was made in the late 17th or early 18th century, and consists of a brass alidade attached to a semi-circle, pivoted upon a heavy stand, which is set with its base horizontal by means of a small brass plummet. The semi-circle and alidade can be rotated in the vertical plane, and the inclination of the line of sight read by a fixed index on the stand.

The semi-circle is graduated in degrees and has a diameter of 4·2 in. The sight rule is a hollow tube fitted with dual sights at each end, one set being within the tube and the other on top of it in the opposite sense.

Inv. 1883–118.

90. PLUMMET LEVEL AND CLINOMETER. Made by Jacob Kranewetter.

This is a German instrument made in 1755, and consists of a hollow wooden stand with a flat base and brass facings. A brass plummet is suspended down one face, and by its position on a scale of degrees engraved on the lower part of the face measures the inclination of the base of the instrument. No sights are provided. A brass knob, screwed into the top of the stand can be detached and used as a plummet ; a cord wound round a drum inside the stand is used to suspend the knob.

The plummet has a length of 4·8 in., which is the radius of the graduated arc. This extends 15° on either side of the vertical. Inv. 1880–201.

91. BALANCE LEVEL. Made by Susse Bros., Paris.

This instrument can be used for testing whether a surface is horizontal, vertical or inclined at 45°.

It consists of a loaded disc, pivoted between the vertical faces of a cylindrical brass case fixed to a brass ruler. Marks engraved on the edge of the revolving disc show by their coincidence with marks on the fixed case whether the ruler, which is placed on the surface to be tested, is horizontal, vertical, or inclined at 45°. The ruler has a length of about 6 in., and one of its bevelled edges is graduated in millimetres. The disc has a diameter of 2 in. Inv. 1857–25.

92. REFLECTING PLUMMET LEVEL. Presented by T. H. Court, Esq.

This type of level was invented by Col. Burel in 1829, and operates upon the principle that in a vertically suspended mirror the eye sees a reflected image of itself at its own level.

The instrument consists of a rectangular frame, suspended in gimbal bearings so as to hang vertical owing to its own weight. The frame contains a piece of plane glass, of which one vertical half is silvered and the other half left free for direct vision of a distant object. A horizontal cross wire bisects the two parts. The observer holds the instrument in front of his eye and moves it until he sees the reflected image of his eye bisected by the cross wire. Any distant object then intersected by the wire will be at the level of his eye.

(*See* " Memorial de l'Officier du Génie," No. 10, 1829.) Inv. 1911–183.

93. REFLECTING PLUMMET LEVEL. Presented by T. H. Court, Esq.

This is very similar to the adjacent Burel type, but has a heavy screw threaded in the base of the frame. By working the screw the inclination of the plane of the mirror can be varied, and adjusted to be truly vertical by means of a test sight. The mirror also occupies much more than half of the frame, leaving a small part only for direct vision. Inv. 1919–331.

94. DE LISLE'S REFLECTING CLINOMETER. Made and lent by T. Cooke & Sons, Ltd., York.

Of the many arrangements for converting a Burel reflecting level into a clinometer, the one here represented, devised by General A. De Lisle, R.E., is the most satisfactory.

A heavy arc is attached to the lower part of the mirror frame and can be turned into the same plane as the mirror for convenience of carriage, or into a perpendicular frame for measuring angles of elevation or depression. In the latter position the weight of the arc causes the mirror plane to take up an inclination to the vertical, which can be varied by means of a movable radial arm, concentric with the arc and carrying a sliding counterpoise at its extremity. The arc is so graduated on its edge that the position of one edge of the movable arm gives the inclination of the mirror, and, therefore, of the line of sight between the observer's eye and its reflection in the mirror. The arc is graduated to read gradients from zero to 1 in 5. Inv. 1921–519.

SPIRIT LEVELS AND CLINOMETERS.

95. SPIRIT LEVEL. Made by Troughton & Simms. Lent by the Royal Society.

This level was constructed in the early part of the 19th century and used in 1831 by J. A. Lloyd, F.R.S., in ascertaining the differences of level between the Thames at London Bridge, Sheerness and various intermediate points. The telescope has a focal length of 28 in. and is finally levelled by means of a 12-in. spirit level mounted at one side parallel to its axis.

The objective lens of the telescope has a 2-in. aperture, and is fixed in the tube, the eyepiece tube being focussed by a rack and pinion arrangement and having a fixed diaphragm and a slide focussing Ramsden inverting eyepiece. The telescope is attached to a transverse horizontal axis, which rests in Y-s on standards fixed to the horizontal plate. The telescope is supported near both ends by vertical screws threaded in the ends of a rigid bar fixed to the horizontal plate parallel to the axis of the telescope. These screws are used in the final adjustment of the telescope axis, which is tested by the main spirit level. This is suspended from the ends of a metal rod fixed on one side of the telescope, parallel to its axis, and has ivory scales graduated to thirtieths of an inch mounted above its bubble-tube. A small level is also fixed transversely at one end of the main level. The bubble of the latter moves over one division of the scale when the telescope is elevated about 2 seconds of arc. The horizontal plate can rotate about a vertical axis, and has a clamp and tangent screw for slow motion. It is attached to a pair of parallel plates, connected by four levelling screws of the usual type. A small circular spirit-level is fixed to the plate above its centre for setting it horizontal.

The telescope can be reversed in its Y-s end for end, or rotated through 180° about its own axis, as in all Y-levels.

(*See* Phil. Trans. Roy. Soc., 1831.) Inv. 1900–155.

96. SPIRIT LEVEL. Made by Cary. Lent by the Royal Society. Plate II, Fig. 2, p. 38.

This level was made about the year 1830 and was used in 1831 by J. A. Lloyd, F.R.S., in measuring the differences of level between the Thames at London Bridge, Sheerness and various intermediate points. It has a 30-in. telescope mounted in Y-s in a manner similar to the ordinary Y-level, but is fitted with an extra spirit level suspended above the telescope, and also has a circular supporting base resembling that of a large theodolite and resting on three footscrews.

The objective lens of the telescope has a 2-in. aperture and is fixed in the tube, the eyepiece tube having a rack and pinion focussing movement. The eyepiece is of the Ramsden inverting type and is also focussed by a rack and pinion movement. Gun-metal collars are shrunk on to the telescope near its extremities and rest in Y-s fixed to the horizontal circle. One of these Y-s can be adjusted vertically by means of a screw. This adjustment serves to level the telescope more precisely than is possible with the footscrews. The 14-in. horizontal circle can rotate about a vertical axis, and has a clamp and tangent screw. It also carries a central $5\frac{1}{2}$-in. compass, graduated in degrees, and a small thermometer. The

supporting base of the instrument consists of two horizontal circles of 14 in. diameter connected by three vertical pillars to which the three footscrews are fixed. Beneath the telescope a 17-in. spirit level is mounted in adjustable bearings, and a 22-in. level of similar construction can be suspended above the telescope from pivots carried by brackets fixed to the end of the tube. Both pivots are adjustable. Each level has ivory scales, graduated to twentieths of an inch mounted above its tube. Small transverse levels are also fixed to the telescope and at one end of the suspended level.

(*See* Phil. Trans. Roy. Soc., 1831.) Inv. 1900–154, S.M. 1938.

97. SPIRIT LEVEL (Troughton type). Presented by A. Stannard, Esq., A.M.I.C.E.

This level was formerly the property of George Stephenson, and was used by him at Chat Moss in the survey for the Manchester and Liverpool Railway, 1829.

It is of the type designed and constructed by Troughton, the spirit-level being rigidly fixed in the telescope, which is not reversible, as in the Ramsden type. Such an instrument, whilst incapable of preliminary adjustment, is very simple and rigid in construction, and is well suited for engineering surveys. A small compass, supported on four pillars, is provided for traversing.

The telescope has an aperture of $1\frac{1}{4}$ in. and a focal length of 15 in., and is provided with stops. The eyepiece tube is focussed by a rack and pinion arrangement actuated by a screw. The diaphragm can easily be disclosed for examination by removing the eyepiece. There are two eyepieces provided, one erect and the other inverting. The bubble-tube is 10 in. long, and has a radius of curvature of about 50 ft., giving a motion of the bubble of $\frac{1}{6}$ in. for every minute of arc.

The compass ring is $2\frac{1}{2}$ in. in diameter, and is graduated to read single degrees. Inv. 1892–21.

98. SPIRIT LEVEL. Made by Troughton & Simms. Lent by the Ordnance Survey.

This instrument was made about the middle of the 19th century, and was used until 1907 for levelling minor lines. The spirit level is attached by adjusting screws to the telescope, which fits in Y-shaped bearings, and can be rotated or reversed in these for adjustment of the line of collimation.

The parallel plate arrangement for levelling the instrument is of the usual type, with four levelling-screws, axis clamp and tangent-screw for slow-motion.

The telescope has a focal length of 12 in., and an aperture of 1·25 in., and is provided with stops. The focussing is carried out at the objective end by means of a rack and pinion arrangement, actuated by an external screw.

The diaphragm containing a horizontal and vertical wire is easily accessible after unscrewing the eyepiece, which is arranged to give an erect image of the staff. The bubble-tube is $7\frac{1}{2}$ in. long, and is graduated in tenths of an inch. The internal radius of curvature of the tube is about 80 ft., giving a movement of the bubble of 0·1 in., corresponding to a change of elevation of 20 seconds.

Inv. 1912–197.

99. SPIRIT LEVEL. Made by Troughton & Simms. Lent by the Ordnance Survey.

This level was made between 1840 and 1850 and was used for levelling of second-order lines. The spirit level is graduated to read 5 seconds of elevation, and is attached to the telescope, which rests in Y-shaped bearings, and can be rotated or reversed for adjustment of the line of collimation. A compass is provided for rough traversing, and an elevating screw permits the telescope to be finally levelled with great accuracy. In the diaphragm are two vertical and one horizontal wires.

The telescope has a focal length of 18 in. and an erecting eyepiece. The aperture is 1·5 in. The eyepiece is adjusted for parallax by a sliding tube arrangement, whilst the telescope is focussed on the staff by a rack and pinion which moves the objective.

The compass-ring has a diameter of $3\frac{1}{2}$ in. and is graduated to read single degrees.

The spirit level tube is 10 in. long, and is graduated at intervals of $\frac{1}{4}$ in., each interval corresponding to 5 seconds of arc. The parallel plate arrangement with four levelling screws is of the usual type, and a slow-motion tangent screw is provided for azimuth setting. Inv. 1912–198.

100. SPIRIT LEVEL. Made by Troughton & Simms. Lent by the Ordnance Survey.

This level was made in 1841 and was used in first-order levelling for the Ordnance Survey. It has a telescope of 2·2-in. aperture and 23-in. focal length, with a 12-in. spirit level attached, reading to single seconds of arc. The telescope rests in Y bearings, in which it can be rotated and also reversed end for end, for adjustments. A small transverse level is also provided on the telescope for rough levelling, whilst the final accurate setting is performed by means of an elevating screw, which moves one bearing.

The instrument has a $5\frac{1}{2}$-in. compass fitted to its alidade for rough traversing, the compass being graduated in single degrees. There is also the usual parallel-plate levelling arrangement, with four screws, for setting the alidade approximately horizontal. A slow motion tangent screw is provided for setting the instrument accurately in azimuth.

The telescope has a micrometer eyepiece, and is focussed on the staff by moving the eyepiece tube.

The spirit-level has an ivory scale above each end, graduated in 1/20 in., each division corresponding to about 2 seconds of arc of elevation. Inv. 1912–199.

101. SPIRIT LEVEL. Made by C. Sickler. Presented by T. H. Court, Esq.

A level of this type, serving also for measuring inclines and distances by means of the elevating screw, is particularly adapted by reason of its compactness and simplicity of construction for preliminary surveys where no great accuracy is required.

It consists of a small telescope and spirit-level separately mounted upon a platform connected with a tripod by means of a ball-and-socket joint of a special type, often employed in small surveying instruments of German construction. This joint permits the orientation of the platform to be varied, whilst leaving it perfectly free to rotate in azimuth about the socket, which is fixed to the tripod. The platform terminates underneath in a metal ball, at the lower end of which is a cylindrical pin. The socket consists of two parts screwed together, an upper spherical dome enclosing the ball, and a lower tubular sheath surrounding the pin. Two levelling screws, set perpendicularly to each other, work in threads in this sheath, and impinge upon a metal collar which encircles the pin sufficiently tightly to prevent shake, but not to hinder the free azimuthal rotation of the pin, and consequently the platform. Opposite the two screws, and likewise impinging on the collar is a spring which takes the pressure of the screws. By means of these screws the platform can be set level in all directions.

The spirit level can be adjusted upon the platform by the small screws at one end of its case, whilst the telescope can be elevated or depressed about an axis at one end fixed in the platform by means of a fine-threaded screw at the other end. The pitch of the screw-threads is half a millimetre, and the movement of this end of the telescope is read to a tenth of a millimetre with the aid of a graduated disc and vertical millimetre scale. For every tenth-millimetre, the line of sight of the telescope moves through an angle whose circular measure is one-thousandth. By this means, as in tacheometry, distances can be measured with fair accuracy.

Inv. 1913–256.

102. SPIRIT LEVEL. Made by Zimmer Bros., Stuttgart.

This instrument, primarily designed for levelling, can also be employed for measuring angles in any plane, and is likewise provided with stadia lines in the diaphragm of the telescope for measuring distances. It is thus a type of cheap, portable, universal instrument, specially adapted for surveys of minor precision.

The special features which distinguish it from an ordinary small level are the graduated semicircle and the peculiar method of attaching the spirit level to the telescope and the whole instrument to the tripod. The lower parallel plate is not attached directly to the tripod head, but to an intermediate knuckle-joint piece, which permits the instrument as a whole to be set with the semicircle in any plane. The spirit level can also be attached to the telescope in two places, one serving when the semicircle is horizontal and the other when it is vertical.

The telescope can rotate on the semicircle, which is graduated to 30 minutes and reads by vernier to 2 minutes, and the semicircle can likewise rotate irrespective of the telescope, thus permitting angles to be " repeated."

The diameter of the graduated semicircle is 18 cm. The parallel plate arrangement is of the usual type, with four levelling screws. Inv. 1876–1196.

103. BREITHAUPT'S COMPENSATION LEVEL. Made by F. W. Breithaupt and Son, Cassel.

This is a later modification of a level designed and constructed by F. W. Breithaupt in 1845, with the idea of minimizing the instrumental adjustments usually necessary as a preliminary to taking levels. The method of weighting the main spirit level and suspending it freely in pin bearings attached to the telescope enables the surveyor to compensate by double readings the errors arising from non-parallelism of the spirit-level axis, telescope axis, and line of sight.

In this level the telescope can be rotated in its collars through a complete half-turn, the extreme positions being determined by mechanical stops. The spirit level, whilst revolving with the telescope, does not rotate, but is kept with its engraved scale uppermost. Consequently the bubble is always visible against the scale, and its variation during the rotation measures the extent to which the axis of the spirit level is inclined to the axis of rotation of the telescope. Such an inclination, if small, will be automatically rendered ineffective provided two readings of the levelling staff are made with the spirit level " centred," one before and the other after the telescope is rotated in its collars through 180°. This double reading also corrects for lack of coincidence between the mechanical axis of rotation of the telescope and the line of sight. The mean of the two readings will be the reading which would be obtained if the three axes of spirit level, telescope rings and vision were mutually parallel. Thus it is not necessary to adjust the instrument beforehand for this parallelism. It is, however, essential that the spirit level itself should be so adjusted that when its bubble is central, its own axis of rotation in its bearings should be horizontal. This can be tested by centring the bubble, reversing the spirit level in its bearings without moving the other parts of the instrument, and reading the bubble again. Half the difference is removed by means of the two capstan-headed screws which fix one end of the bubble tube to its case. To enable the spirit level to be so reversed, one bearing pin can be withdrawn from its supporting bracket.

The lower part of the instrument is provided with a circular box level, which serves to set the main axis nearly vertical by means of the footscrews. No attempt is made to render this axis exactly vertical, as the telescope is always finally levelled by means of the elevating screw. The head of this latter is divided, and serves to measure very accurately small gradients. The diaphragm of the telescope has two horizontal subtense wires in addition to the central levelling wires, so that the instrument can be used to measure distances.

The " suspension " spirit level of the type here shown was soon superseded in compensating levels by Amsler's two-sided " reversion " level, which is much less liable to be injured by shocks than Breithaupt's pattern.

See " Dingler's Polytechnisches Journal," Bd. 153, p. 401, 1859.

Inv. 1876–1198.

104. COOKE'S REVERSIBLE LEVEL (14-in.). Made and lent by T. Cooke & Sons, Ltd., York.

The Y-s of an ordinary reversible level are replaced in this instrument by a strong and rigid socket, from which the telescope can be bodily withdrawn and replaced after reversion end for end in the " collimation " adjustment. Accurately turned flanges on the telescope fit in collars fixed at the ends of the socket. A stop flange at the eyepiece end of the telescope abuts against the end of the socket when the telescope is in the correct position, and can be fixed to the socket by a screw. The socket is fixed to the horizontal rotating arm by end fittings which permit it to be adjusted on this arm by elevating or depressing one end. The main spirit level is similarly attached in adjustable bearings above the socket, parallel to its axis. A small cross level is fitted at right angles to the axis above the socket at one end. Each division of the main level is 0·1 in. long, corresponding to 20 seconds of elevation.

The rotating arm carries a central circular compass, of 3·5 in. diameter, graduated in half-degrees, and read by a prismatic reader. The needle can be lifted from its pivot and clamped by turning a screw at one end of the arm. The conical socket carrying the axis of rotation is fixed to the tribrach, in the arms of which engage three footscrews. The feet of these are firmly attached to a trivet stage which can be screwed to the tripod head. This stage has three pointed feet which serve to fix the instrument to a platform when the tripod is inconvenient.

The telescope has an objective of 14 in. focal length and 1·55 in. clear aperture, and an inverting screw-focussing eyepiece magnifying 28 times. The objective tube is focussed by a rack and pinion arrangement actuated by a screw at one side of the telescope near the eye end. The glass diaphragm has two vertical and one horizontal lines engraved upon it, whilst short horizontal lines etched parallel to the sight line can be used for stadia observations. Inv. 1921–560.

105. DUMPY LEVEL (9-in.). Made and lent by C. F. Casella & Co., Ltd.

The compactness and rigidity which are the chief features of the dumpy level have been increased in instruments of recent construction by the employment of an internal focussing lens, which moves between the fixed objective and diaphragm. The telescope tube can thus be rendered more compact, dust-proof and water-tight, whilst the act of focussing is less likely to disturb the line of collimation.

In the instrument exhibited, the telescope has a focal length of 9 in. and a clear aperture of 1·4 in. and is provided with a tribrach mounting, with three levelling screws. A 2-in. ring, divided every 2°, is fitted round the upper rim of the tribrach and enables the azimuth angle to be read by means of an index on the telescope socket. A tangent clamp and fine motion screw are also fitted to the tribrach. The feet of the levelling screws pass through a locking plate having a threaded central aperture to receive the clamping piece which attaches the instrument to its tripod.

A sensitive tube level, the casing of which also supports a small circular box level, is mounted in adjustable bearings at one side of the telescope.

The eyepiece of the telescope is inverting and screw focussing, and has a magnification of 24 diameters. Inv. 1921–733.

106. DUMPY LEVEL. (10-in.). Made and lent by E. R. Watts and Son, Ltd.

This is a modern dumpy level having a fixed objective of 1·5 in. aperture and a fixed glass diaphragm sealing the other end of the 10-in. telescope tube, which is thereby rendered dustproof; a movable internal concave lens is actuated by an external milled head for focussing, and a screw-focussing inverting eyepiece is provided.

A 5-in. bubble tube is adjustably mounted on the left of the telescope and has a sensitivity of 20 seconds of elevation per 0·1 in. division of its scale; by means of a hinged reflecting mirror mounted above its scale, it is read by the operator without moving his other eye from the telescope.

The telescope tube is permanently fixed to the inner vertical axis of the instrument and rotates within the conical socket of the tribrach levelling base, which has the usual three footscrews connecting it to the trivet stage; dust-proof caps are fitted above the heads of the footscrews and their feet are firmly gripped in the grooves of the trivet stage; this latter has a central screwed aperture for attachment to the tripod head, but has also three pointed feet for mounting on a platform without the tripod. The axis clamp and tangent screw of the azimuth motion are of the usual type. Inv. 1922–443.

107. ZEISS PATTERN LEVEL. Made and lent by E. R. Watts and Son, Ltd.

The optical arrangements for adjusting the collimation axis of the telescope and viewing the bubble are the same in this instrument as in the well-known Zeiss-Wild level, but the elevating screw mechanism and tribrach are of the makers' own design.

In order to obviate the necessity for reversing the telescope end for end in the collimation adjustment, it is provided with two similar objectives, one fixed at each end of the tube, and an internal focussing lens. The eyepiece can be fitted at either end, and the nearer objective lens then becomes the diaphragm; each lens is graticuled for this purpose. A screw-focussing eyepiece tube is fitted at the normal eyepiece end, and the objective cap has a central sheath aperture in which the eyepiece can slide at the other end. The normal diaphragm lens has horizontal stadia lines as well as the usual cross lines; the other lens has only a simple cross.

The telescope is supported in a central horizontal socket, in which it can rotate through 180° about its own axis. The bubble tube is adjustably fixed at one side of the telescope and rotates with it in the socket; it has apertures at the top and bottom for reading its bubble before and after rotation. A system of prisms mounted above the bubble tube permits the observer to view the two ends of the bubble in his normal position for observing the staff, the bubble being viewed with the left eye and the staff with the right.

The socket supporting the telescope is itself mounted upon an elevating platform which can turn in azimuth about the vertical axis of the tribrach. The telescope socket is pivoted centrally to this platform about a horizontal axis intersecting the main vertical axis of rotation, and can be rotated about this pivot by means of a micrometer elevating screw threaded in the platform at one end;

the screw does not impinge on the socket, but on an intermediate lever arm pivoted horizontally at the other end of the platform and in contact with the socket near this pivot. A spring connecting the socket and platform keeps the former pressed against the lever arm. By this arrangement the weight of the telescope is taken off the elevating screw and its rotation about the central pivot is only a small part of what it would be without the lever arm.

The micrometer drum of the elevating screw is divided to read single minutes of elevation of the telescope and can be used for measuring distances ; the stadia lines of the telescope diaphragm can also be used for this purpose.

Inv. 1922–440.

108. Y-LEVEL (14-in.). Made and lent by E. R. Watts and Son, Ltd.

The telescope of this level has a rack-focussing objective of 1·3-in. aperture and 14-in. focal length. A 6-in. bubble-tube is mounted adjustably beneath it and has a sensitivity of 22 seconds per 0·1 in. division of its graduations.

The telescope is supported in Y-s by means of gun-metal collars, 8 in. apart, and can be rotated in its Y-s or reversed end for end in the usual manner. The Y-s are permanently fixed to a supporting platform of very rigid construction, but two screws threaded in the arms of one Y permit the telescope to be raised or lowered in that bearing to take up wear. The hinged retaining clips of the Y-s have metal springs attached which keep the collars pressed down on their bearings ; one of these springs has a pointed toe which engages in a groove notched in the collar when the telescope is in the normal observing position, *i.e.*, the bubble vertically below its axis.

The supporting platform has a conical axis and can rotate in azimuth within the tribrach levelling base ; an axis clamp and tangent screw are provided. Three footscrews are threaded in the tribrach and have their feet firmly clamped in a trivet stage, which can be screwed to a tripod head or can stand on a platform by means of its three pointed feet. The footscrews have dustproof caps threaded in the tribrach to protect their heads and to take up wear.

Inv. 1922–442.

109. PRECISE LEVEL (16-in.). Made and lent by T. Cooke & Sons, Ltd.

A " precise " level, designed for work of the highest possible degree of accuracy, in addition to its greater sensitivity and power, possesses several features not found in ordinary levels. The chief characteristics are the additional facilities for finally levelling the telescope by means of a micrometer screw and a very sensitive bubble, which is read by a supplementary optical arrangement at the same time as the staff, and the protection of the bubble and all movable parts affecting the axis of collimation from temperature changes. In the level exhibited, which was introduced by the U.S. Coast and Geodetic Survey about the year 1900, the main bubble tube is sunk well inside the outer telescope tube, which is also covered by felt cloth. A system of mirrors and a supplementary telescope with its eyepiece at binocular distance from the main telescope, enable the observer to read at the same time the staff with his right eye and the ends of the bubble with his left.

The main telescope has an objective of 1·7-in. aperture and 16-in. focal length, mounted in a tube containing the rack focussing eye-piece tube. The objective tube is pivoted near the object end to the cloth-covered outer tube and near the eyepiece end rests on a micrometer screw. By turning this the objective tube can be slightly inclined in the vertical plane through the staff and station point until the bubble, which is fixed to it, is centred. The outer tube itself can rotate about the vertical axis of the instrument and has a tangent clamp and screw for slow-motion in azimuth. A tribrach with three footscrews supports the whole instrument and serves to level it approximately, with the aid of a small box level on the outer telescope tube. The telescope can be lifted from contact with the micrometer screw and clamped inside the outer tube by a lever bar near the micrometer. This arrangement preserves the micrometer from unnecessary use and friction. The micrometer drum is graduated in 100 divisions, each corresponding to the 2-mm. divisions on the main bubble, *i.e.*, to 2 seconds of elevation. The eyepiece tube of the main telescope has a cross-wire diaphragm, with two horizontal stadia lines ; two inverting eyepieces, of magnifications 32 and 44, are supplied. The supplementary telescope has a plain aperture eyepiece and two diagonal reflecting prisms which, in conjunction with a plane mirror fixed to the outer telescope tube, reflect the image of each end of the bubble and scale down the axis of the telescope. All the parts of the main telescope which affect the adjustment of its line of collimation are made of " invar." Inv. 1922–206.

110. PRECISE LEVEL (13-in.). Made and lent by E. R. Watts and Son, Ltd.

The special features of this level are the bubble-tube and an optical arrangement mounted in front of the objective lens to enable the staff to be read accurately to 0·001 ft. and by estimation to 0·0001 ft.; both these fittings are modified examples of the ones originally mounted on the Zeiss Precise Levels about 1913.

The telescope has a screw-focussing inverting eyepiece and a fixed glass diaphragm, engraved with cross lines and horizontal stadia lines. The horizontal cross line is in the form of a very narrow Y, having its stem horizontal and its arms intersecting at a small angle on the vertical line; by this arrangement any division of the staff is bisected by one half and enclosed by the other half of the Y. If the telescope axis, when levelled, does not bisect a staff division, the optical axis is displaced slightly along the staff by means of the ante-objective fitting until a division is accurately bisected. The fitting consists of a plane glass slab of cylindrical shape, pivoted horizontally within a cap-sheath fitted over the objective end of the telescope; the slab can be rotated about its pivot axis by means of a radial lever fixed on the axis and having a pinion wheel at its outer end, which engages in the toothed face of a fixed arc mounted on the cap sheath. The opposite face of this arc is visible to the observer, and is graduated into 20 parts, each division representing 0·001 ft. on the staff, *i.e.*, the optical axis is displaced vertically by this amount when the slab is pivoted through the corresponding arc; an index mark on the rotating lever serves to measure the arc to a tenth division, *i.e.*, to 0·0001 ft. The telescope objective has an aperture of 1·8 in. and is fixed in the tube; an internal lens operated by an external milled head is provided for focussing the staff image on the diaphragm.

The micrometer elevating mechanism of the telescope, the Zeiss pattern bubble-tube and the tribrach mountings, with clamp and tangent screw for slow azimuth rotation, are of the same type in this instrument as in the small Zeiss pattern level by the same makers, and are described in connection with the adjacent exhibit (Cat. No. 107). The micrometer drum of the elevating screw is graduated into 20 parts, each corresponding to an elevation of 1 : 10,000, whereby distances can be accurately estimated.

This type of level is used in conjunction with an Invar Precise Levelling Staff of the type represented in an adjacent exhibit (Cat. No. 125). Inv. 1922–441.

111. CLINOMETER. Made by W. Bandermann, Berlin. Presented by T. H. Court, Esq.

This clinometer is not provided with sights, but has two plane edges at right angles and a movable spirit-level with a vernier at one end. The instrument is set on the face of the rod and the level rotated until the bubble is centred, when the zero mark of the vernier gives the inclination to a sixteenth of a degree. The arc over which the vernier moves is graduated in half degrees, each of the eight intervals between the vernier graduations being seven-eights of a half degree.

An instrument of this type is principally used for setting levelling-rods vertical, or for measuring the gradient of a rod used for determining distances in cadastral surveys. It can be set upon some kind of sighting rod and used for measuring gradients or for levelling. The spirit level is very sensitive, and the bubble moves about 0·5 cm. for every variation of a sixteenth of a degree in the inclination. Inv. 1917–38.

112. CLINOMETER. Made by Thos. Jones, London. Presented by the Admiralty.

This instrument was made in the first half of the 19th century, and is used for measuring the elevation to the horizontal of any inclined plane on which it can be set. It is not provided with sights.

It consists of two brass rulers, hinged at one end. The upper ruler carries a sensitive 6-in. spirit level and an index, which moves over a graduated brass arc fixed to the lower ruler. This latter is placed upon the surface to be measured and the other ruler revolved until the bubble of the level is centred, when it can be clamped by a screw on the index plate and the reading taken.

The arc is graduated in degrees from 0° to 50°. Inv. 1911–174A.

113. CLINOMETER. Presented by the Admiralty.

In this instrument two brass rulers are hinged together at one end. The upper one has perpendicular sights at each end, each of which has both an aperture backsight and a cross-wire foresight, and carries an index plate which moves over a graduated arc fixed to the lower ruler and can be clamped to this arc by a screw. A 5-in. spirit level is supported parallel to the upper ruler in bearings on the sights. The lower ruler has a socket for fixing the instrument to a stand.

In using the instrument, the upper ruler is lowered until it rests on the lower and the instrument is levelled by the spirit level, after which the upper ruler is raised until the object whose angular elevation is required is sighted, and the reading of the arc taken.

The arc has a radius of 4 in. and is graduated from 0° to 30° in degrees, read by estimation to tenths. Inv. 1911–174B.

114. ABNEY LEVEL AND CLINOMETER. Made by Cary, London. Presented by Captain H. G. Lyons, F.R.S.

In a hand-level it is desirable that the object sighted and the levelling mechanism should be simultaneously visible. The combined level and clinometer designed by Capt. Abney, R.E., about the year 1870, utilizes the idea of reflecting the bubble of a spirit level into the line of sight of the sighting tube by means of a diagonal mirror fixed in one half of the latter, the other half being left free for sighting the object. This device had been previously used on a sextant.

In the instrument exhibited, a graduated semicircle is rigidly fixed to the rectangular sighting tube, which has a pin-hole aperture and a diagonal mirror fixed beneath a slit in its upper face, vertically beneath the centre of the arc. Through this centre passes an axis, carrying a small transversely mounted spirit level at one extremity and a vernier arm near the other, which terminates in a large milled wheel. On rotating this wheel the spirit level is set at any angle to the line of sight, the angle being measured by the position of the vernier on the graduated arc. The cover of the spirit level has apertures above and below, the latter permitting an image of the bubble to be seen after reflection on the mirror, whilst the former is used when the clinometer is set on the surface whose gradient is required. The arc is graduated in degrees up to 60° on both sides of the vertical, and reads by vernier on the movable arm to 10 minutes. It also has a scale of gradients to 1 in 1, read by the edge of the vernier.

The sighting tube is $4\frac{1}{2}$ in. long and the graduated arc has an effective radius of 1 in. Inv. 1914–220.

115. ABNEY LEVEL AND CLINOMETER. Made by Elliott Bros., London. Presented by T. H. Court, Esq.

This example differs from the preceding one in minor details. The graduated arc is fixed to the spirit level and revolves with it, being read for angles up to 45° either way by means of a fiducial mark on the supporting bracket, which is fixed to the sighting tube.

Scales of gradients up to 1 in 1 are also marked on the arc beyond the degree graduations and are read by the bevelled edges of the supporting bracket. The edge of the arc is milled, and gears with a small pinion wheel centred in the fixed bracket and rotated by a milled screw. This permits the spirit level and arc to be rotated more slowly and evenly than in the other form. The sighting tube has a circular section, which is not so convenient when the instrument is to be placed on the slope as the rectangular type. Inv. 1913–254.

116. ABNEY LEVEL AND CLINOMETER.

This is similar to the preceding examples, but has also a $1\frac{1}{4}$-in. compass fixed on the upper surface of the sighting tube. The compass ring is graduated in degrees, numbered every 10° by quadrants from the N—S line. Inv. 1887–62.

117. FIELD CLINOMETER (Mark III). Made by J. Casartelli & Son.

This is a modern Service clinometer for measuring to the nearest minute the angle of elevation of a plane surface. The angle is measured to the nearest degree by a rotating arm which traverses a fixed graduated sector attached to the base. The arm is slightly curved on its upper and lower surfaces, and carries a sliding spirit level whose position, when the bubble is central with respect to the scale graduated on the arm, gives the number of minutes in the angle.

There are two flat mutually perpendicular base plates, one painted black and the other red, and the sector of degrees is graduated on both sides, one set numbered in black from 0 to 44 and the other in red from 50 to 89, for use with the corresponding base. The black base is used for angles below 45° and the red for those above. The radial arm has a radius of 5 in., and is pivoted at the centre of the graduated sector. The other end of the arm has a spring clutch, with a toothed face engaging in the teeth on the inner face of the sector and locking the arm in any desired position. The scale of minutes on the arm extends through a complete degree and occupies a length of 2 in. The arm is thus curved in a circle of radius about 9·5 ft. There are such scales of minutes on the front face and the rear face of the arm, the former numbered with the zero nearest the pivot and the latter in the reverse direction. The front scale is used with the black base and the rear scale with the red one. Inv. 1922–42.

118. WATKIN CLINOMETER. Made and lent by Messrs. Cooke, Troughton & Simms, Ltd.

Instead of a graduated arc, this type of clinometer is provided with a rotatable drum, upon the face of which is a graduated spiral groove, upon which is recorded the amount of elevation of the surface tested.

The bubble level is mounted within a gunmetal frame which has two surfaces accurately machined at right angles to each other. One end of the level is pivoted to the frame, and the other end is kept pressed against the base of the drum which rotates upon a threaded screw carried by the frame. As the drum rotates, an index fixed to the frame records on the scale the resulting elevation of the free end of the level above the pivoted end, and hence, when the bubble is centred, the elevation of the plane upon which the frame is set.

No sights are provided with this instrument, which is designed for recording the slope of a plane surface with respect to the vertical or horizontal, according to which of the two plane surfaces of the instrument is in contact with the surface tested.

The range of the drum scale is from 40 minutes below to 45° above zero, the first 5° being subdivided by dots to 1 minute; thereafter lines indicate every 5 minutes. Inv. 1925–4.

119. INDIAN CLINOMETER. Made and lent by Messrs. Cooke, Troughton & Simms, Ltd.

In this clinometer, one sight is fixed and the other is movable over a graduated scale engraved upon the vane; the position of the movable sight registers the inclination of the line of sight.

The instrument consists of a hollow bubble arm mounted upon a gunmetal base, which has three studs on its lower face. The bubble arm is pivoted at one end to the base, and carries an adjusting screw at its other end for setting the bubble central. A folding sight vane is fitted to each end of the bubble arm, the shorter vane having a fixed aperture backsight and the longer one carrying the sliding foresight. The latter vane has two scales engraved upon it, one of degrees, subdivided to 20 minutes, and the other of tangents. The range of the scale is 0°–23° of elevation or depression. Inv. 1925–5.

ACCESSORIES.

120. AXIS LEVEL. Lent by the Royal Society.

In large astronomical and surveying instruments, specially long and sensitive levels are generally provided for testing the horizontality of the telescope axis. The levels are usually fitted above the axis by bearing forks, but are sometimes suspended from it by curved brackets. The one exhibited is of the latter type, and was probably made in the early part of the 19th century. It has a bubble tube about 15 in. long by 1¼ in. diameter, and an ivory scale mounted on the casing and divided in tenth-inches.

The brass casing of the bubble tube has end plates which fit loosely upon screwed vertical pins and can be clamped in any desired position by upper and lower capstan nuts threaded on the pins. The latter project from a horizontal brass tube, somewhat longer than the bubble tube and having the suspension brackets fastened to its ends. The upper portions of these brackets are curved

and their ends turned over and provided with inverted V-plates which rest on the telescope axis. The scale divisions are numbered symmetrically from the centre. A small transverse spirit level is mounted on one end of the casing of the main level. The vertical pin at one end of the base tube is slightly adjustable laterally by means of capstan nuts. Inv. 1900–167.

121. SET OF BUBBLE TUBES. Made and lent by T. Cooke & Sons, York.

This exhibit comprises twenty-two bubble tubes of various shapes, sizes and sensitivities, all except two being unmounted.

Six are of the circular or " pill-box " type, the upper surface of the container being internally ground spherical, so that the bubble, when centred, occupies the space inside a circle engraved on the glass. Two of this type, which are not very sensitive and are only used for rough levelling, are shown mounted in brass cases, attached to the base-board.

The remaining sixteen are tube levels, six of them having their glass containers bent as a whole into a circular shape, and the other ten being straight tubes, internally ground to various curvatures according to the desired sensitivity. The first six are not very sensitive, and are of the type used by carpenters, masons, etc. The other ten are used on surveying instruments, etc., and are usually mounted in brass cases, attached to the instrument by adjustable screws.

On the larger levels of this type, division marks are graduated at 0·1 in. interval for reading the positions of the ends of the bubble, and the sensitivity is indicated by the angle of elevation of the level necessary to cause the bubble to move over one division. The most sensitive one exhibited has a sensitivity of 1 division per 5·5 seconds of elevation. This particular bubble tube has also a separate chamber at one end. When the bubble expands owing to increasing temperature, a portion of the air can be detached and transferred to the supplementary chamber through a small aperture in the separating wall, and the bubble thus reduced to its normal size. Inv. 1921–563.

122. LEVELLING ROD. Lent by T. H. Court, Esq.

This staff was made in the 18th century and consists of a graduated wooden rod 6 ft. long, 1¼ in. wide, and ⅝ in. deep, over which can slide a sighting vane, which has a sharply defined diamond of dark wood inlaid upon a face of light wood, and fits closely to the face of the rod. The vane is moved by the staff holder until the observer signals that it is in line with the telescope, when the former takes the reading of an index mark on the bevelled edge of a small opening in the vane. This method of levelling was superseded about 1835 by the modern one, in which the observer himself reads the staff through the telescope, an improvement rendered possible by the improved telescopes used.

The face of the staff is graduated both in inches, divided to tenths, and also in hundredths of a foot along its whole length save the top 3 in. Another rod of equal length but slightly smaller section can slide along the back of the first, being retained in position by a metal band which serves as a friction clamp. This second rod is not divided and merely serves as a stand for extending the graduated rod. Both are tipped with brass at their ends.

A second vane, similar to the first, is supplied. Each has a circular shape, of diameter 5 in. The inlaid diamond has diagonals 5 in. and 2¼ in., the longer bisecting the vane horizontally. Pins and a metal spring fixed to the back of the vane keep it in position on the rod. Inv. 1917–107.

123. LEVELLING STAFF. Lent by the Ordnance Survey.

This is an inextensible wooden staff 10·5 ft. long, having a rectangular section 2 in. wide by 1 in. deep, and is graduated in hundredths of a foot so as to be read through the telescope by the observer himself. The face of the staff is sunk slightly below the edges to preserve the graduations from abrasion.

The graduation marks consist of black horizontal bands 0·01 ft. wide at uniform intervals of 0·01 ft. apart. The 0·1-ft. bands stretch right across the staff, the remainder occupying the left portion only, save at the 0·05-ft. points, where there is an additional black mark to the right of the corresponding white band. Large black numbers, horizontally set, mark the feet, the tenths being marked by smaller black numbers set vertically. A diamond is used instead of the number " five " on the latter graduations, and a dot is placed near the " nine " to distinguish it from the " six " when the numbers are seen inverted in the field of the telescope. Inv. 1914–422.

124. GRADUATED RULES FOR LEVELLING RODS. Made and lent by E. R. Watts & Son, Ltd.

This exhibit illustrates the method of engraving wooden and invar rules for their levelling rods now adopted by Messrs. Watts. The portions to be painted black on the white surface of the rule are first gouged out to a sufficient depth and the black filled in nearly flush with the white surface ; the black bands are thus rendered very durable.

Two of the rules are portions of those used in the ordinary Sopwith type of staff, one showing the graduations cut and the strips gouged out, the other the finished rule, with the strips filled in and figured. The third rule is made of invar, for use in a precise levelling rod, and the bands of black at 0·02-ft. intervals are not so wide as in the other type of rod, where they are exactly 0·01 ft. wide. In the latter case the lower edges of the bands define the odd hundredths of a foot and the upper edges the even hundredths ; in the invar rod, only the upper edges are used, the cross wire of the telescope being made to coincide with this edge in taking a reading. The graduations are not figured on the invar strip, but on the surrounding wood of the rod, as in the adjacent exhibit of a portion of the complete rod. Inv. 1922–446.

125. PORTION OF INVAR PRECISE LEVELLING ROD. Made and lent by E. R. Watts & Son, Ltd.

The advantages of a metal scale for levelling staves have until recently been counterbalanced by the tendency of such scales to expand when heated, and the difficulty of ascertaining their temperature in order to apply the necessary correction. The invention of " invar "—a nickel-steel alloy of negligible temperature coefficient—has now led to its employment in levelling rods used in precise surveys. The example shown is the lower portion of such a rod.

The invar rule is painted white and engraved with black bands at intervals of 0·02 ft., every fifth band extending over the complete width (about 2 cm.) of the rule, and the others over half its width. The rule is then screwed into a central recess in the face of the wooden rod, which has an I section for strength and lightness, and is shod with a metal shoe terminating in a flat base plate ; the bottom of the invar rule is flush with this plate. The face of the wooden rod is painted white and numbered opposite the marks corresponding to intervals of 0·1 ft. on the invar rule. The numbers are in black, and are inverted so as to be seen erect in the telescope of the level ; a V is used instead of 5 and an N instead of 9. At the divisions of the rule corresponding to an integral number of feet from the base plate, large red numbers are painted on the wood, and are twice repeated in smaller sized numbers on the opposite side of the face so that the observer has always one of the red numbers in the telescope field.

In estimating the position of the cross wire with respect to the graduated scale of the rod, the nearest 0·02-ft. mark is taken and the remaining interval found either by elevating or depressing the telescope by a fine-motion screw, or by moving an optical device which causes the image of the rod to be raised or lowered in the telescope field. The position of the cross wire is thus readily found to 0·001 ft. Inv. 1922–467.

BAROMETERS AND HYPSOMETERS.

126. MOUNTAIN BAROMETER. Made by West. Lent by G. J. Symons, F.R.S.

This instrument is a closed cistern mercury barometer of the type common in the late 18th and early 19th centuries ; it is specially adapted for portability and thus capable of employment in measuring altitudes. When it is being transported, the mercury can be forced up so as to fill the tube completely by turning an adjusting screw, which depresses the flexible leather base of the cistern. The aperture in the wooden case, used for reading the height of the mercury and the temperature, can also be closed by a rotating brass sheath.

The barometer is graduated in inches, and reads by a vernier index, operated by a rack and pinion mechanism, to 0·002 in. A thermometer, provided with Centigrade and Fahrenheit scales, is placed near the top of the instrument. A suspension ring is fixed at the top, and is covered by a ferrule when the instrument is being carried. A screw cap at the bottom likewise serves to enclose the adjusting screw which operates on the cistern. The wooden case which encloses the lower part of the tube is graduated in inches, so that the instrument can serve as a rough measuring rod. Inv. 1893–134.

127. MOUNTAIN BAROMETER. Made by Dollond. Lent by G. J. Symons, F.R.S.

This resembles the adjacent instrument, made by West, in its general characteristics of compactness and portability, but differs in the arrangement of the cistern. This is of the usual flexible base type, but has a supplementary syphon tube, connected to the cistern by a narrow neck, which can be closed by means of a cock. When the instrument is being used, the cock is opened, and the mercury allowed to attain a fixed height in the syphon tube. This is the zero of the barometer tube scale. For transporting the barometer, the mercury is withdrawn from the syphon tube and the cock closed, after which the flexible base of the cistern is depressed by means of the adjusting screw until the mercury completely fills the barometer tube.

The barometer tube is graduated in inches, and read to 0·002 in. by a vernier attached to the movable index. A thermometer with Centigrade and Fahrenheit scales is fixed near the top. The window for reading this and the barometer can be closed by means of a rotating brass shutter, and a similar shutter at the bottom of the instrument serves to protect the cistern and syphon tube when required.

Inv. 1893–133.

128. MOUNTAIN BAROMETER. Made by Troughton & Simms.

The Gay-Lussac syphon-tube mercury barometer, in which both the long and short tubes are closed completely at the end, but a small aperture in the side of the short tube permits the air to enter whilst preventing the mercury escaping, was essentially a portable instrument, and was, therefore, often used for measuring altitudes prior to the invention of the aneroid. The instrument exhibited is of this type, and was constructed probably about 1840.

The barometer tube is enclosed in a brass case, at the ends of which are cork cushions. Scales graduated directly to 0·02 in. and read by movable verniers to 0·001 in. are engraved upon the case opposite the ends of the mercury. Each vernier has an index which can be set level with the top of the mercury column. The difference between the two readings then gives the height of the barometer. A thermometer, with Centigrade and Fahrenheit graduations, is fixed near the centre of the tube. This instrument is attached by brackets to a wooden stand, and can be set accurately vertical by means of three screws threaded in the lower bracket with their ends pressing against the case of the barometer. For mountain barometers a tripod stand was usually provided. Inv. 1907–65.

129. ANEROID BAROMETER. Made and lent by W. F. Stanley.

This instrument was made about 1890, for the use of surveyors in measuring altitudes up to 4,000 ft.

The zero mark of the altitude scale corresponds to a height of 32 in. in the mercury barometer. The altitude scale has a diam. of 3·5 in., and is graduated every 10 ft., single feet being estimated. The movable glass cover carries an index mark, which is set to the last height read, and a small lens for facilitating reading. The altitude scale is slightly raised on a step so that its inside graduated edge is flush with an aluminium plate fixed to the tip of the hand and provided with a mark. By this arrangement errors due to parallax are avoided. The instrument is compensated for temperature variations. Inv. 1893–119.

130. WATKIN ANEROID BAROMETER. Made by J. Hicks.

In aneroid barometers many attempts have been made to provide scales suitable for a very extended range of altitudes. This instrument shows the three concentric circular scale arrangement devised by Major H. S. S. Watkin, by which altitudes from zero to 10,860 ft. can be measured. The zero graduation corresponds to a height of 31 in. in the mercury barometer.

Altitudes from zero to 3,440 ft. are marked at 20 ft. intervals on the outermost scale, which has a diameter of 3·6 in. The middle scale, of diam. 2·9 in., records altitudes from 3,440 ft. to 6,860 ft., whilst the innermost scale, of diam. 2·2 in., completes the range to 10,860 ft., every 20 ft. being marked on each scale. The corresponding mercury barometer scales are marked at 0·02 in. intervals from 31 in. to 20·8 in. To show which scale should be used, an indicator exhibits the number 1, 2 or 3, corresponding to the outer, middle and inner scales respectively. The number indicated is marked upon a plate worked by

the mechanism, and is automatically altered when the barometer hand reaches the end of the scale concerned. The breaks in the circles are indicated by black bars.

The revolving glass cover carries an index hand, which can be set to the last reading taken.

The instrument is compensated for temperature variations.

(*See* British Patent Specification, No. 14730, of 1886.) Inv. 1907–67.

131. EARLY THERMOMETRICAL BAROMETER. Made by Francis J. Hyde Wollaston. Presented by the Rev. T. P. W. Worswick.

A new " thermometrical barometer " of the type here exhibited was invented by Wollaston and described by him before the Royal Society in 1817. The one exhibited was made before 1821. It is essentially a very sensitive " boiling-point " thermometer, whereby the temperature at which water boils may be found to within a thousandth of a degree Fahrenheit, and the altitude of the place determined accordingly.

The bulb of the thermometer is spherical and has a diameter of about an inch. The tube has a length of 30 in. and a very fine bore, so that one degree Fahrenheit corresponds to a movement of the mercury in the tube of 4 in. This is measured by means of a brass scale fixed on the face of the rod which supports the tube. The scale is graduated to read 0·02° F. directly, and 0·002° F. by means of a movable vernier. The rod carries a double walled tin cylinder surrounding the bulb of the thermometer. The cylinder can be detached and partly filled with water, which is then boiled by means of a spirit lamp so that the steam surrounds the bulb of the thermometer.

Along the side of the rod is attached a strip of paper on which is marked a scale of corrections to be applied to the temperature scale, owing probably to inequalities in the diameter of the bore of the tube.

(*See* Phil. Trans., 1817, No. XIII and 1820.) Inv. 1914–735.

132. HYPSOMETER. Made and lent by L. Casella.

Although not so accurate as a standard barometer, a hypsometer for determining altitudes by means of the boiling point of water is more convenient for rapid surveys in mountainous districts. The example shown is of the " pocket " type much used by Alpine travellers. Its thermometer is graduated from 180° to 215° F. by 0·02°.

The apparatus consists of a brass water container and steam jacket, in which the thermometer is suspended and which is fixed above a small spirit lamp for boiling the water. A brass case surrounds the lamp, which is further screened from wind by means of a black japanned tin box, provided with air holes covered by wire gauze. The thermometer is suspended with its bulb inside an inner tube connected to the boiler. An outer telescopic tube surrounds this and serves to support the thermometer in addition to forming a steam jacket enclosing the mercury as much as possible. The steam escapes by a hole in the top of this outer tube. In improved hypsometers it is made to retrace its path downwards and escape at the bottom of the steam jacket.

With this apparatus altitudes are determined by means of specially prepared tables provided with the instrument, giving the heights above sea level corresponding to a particular temperature at which water boils, and also corrections to be made for latitude, mean temperature of the air, and decrease of gravity with increase of elevation. Inv. 1893–149.

MEASUREMENT OF ANGLES.

Primitive notions of direction were probably derived from celestial observations, and the practice, universal among early civilizations, of orienting temples in a definite direction may be considered to mark the commencement of angular measurement. An early Egyptian instrument (*merkhet*), used by the astronomer priests to determine a meridian line is represented in the Astronomy Collection, and illustrates the antiquity of the plummet as a sighting appliance for determining direction and time. The " gnomon," or primitive sun-dial, has much in common with the Egyptian " merkhet," and was possibly derived

from it. The evolution of the later Greek and Roman instruments for measuring celestial and terrestrial angles can readily be traced from these two primitive appliances for meridian, direction and time determination. For the execution of ordinary surveys upon a horizontal plane, the ancients relied principally upon the direct measurement of the sides of triangles or quadrilaterals, supplemented partly by an empirical theory of similar triangles, and partly by a frequent use of right angles. For these purposes they employed either a species of "surveyor's cross," such as the Roman "Groma" (*see* No. 135), by which two rectangular directions could be simultaneously sighted, or else a "dioptra," consisting of a rotatable sight-rule, which could be successively directed in two mutually perpendicular directions defined by stops or index lines. Hero of Alexandria (*circa* 50 A.D.), described such a "dioptra" in which the sight-rule could rotate over a circular plate which could be set in any desired plane. For astronomical purposes, such as latitude determinations, the circular plate was graduated in degrees, and the instrument thus arranged bore a striking resemblance in appearance and function to the modern altazimuth.

The development of portable astronomical instruments, such as the astrolabe and quadrant, by the Arabs, and the study of trigonometry, led to a modification of surveying methods, consisting in the increasing substitution of angular for linear measurement, and the corresponding evolution of portable surveying instruments for measuring angles in any plane. Hence arose the surveying theodolites, graphometers and quadrants of the Renaissance period, the former being principally used for measuring angles in a horizontal plane and the latter for measuring altitude angles. Both are essentially simple modifications of the astronomical and nautical astrolabes of the Arabs, the divided circle, semicircle or quadrant being mounted upon a stand, usually by means of a knuckle or universal joint, and provided with a pivoted compass needle for orientation. At this period many surveyors preferred instruments based on linear rather than circular graduated scales. The Geometrical Square of Purbach was of this type, and was an obvious modification of the quadrant. Other linear instruments, however, such as the cross-staff and jacob-staff, were copies of Ptolemy's Triquetrum, in which the chord of an angle was measured on a linear scale instead of its arc on a circular one.

In 1571, Thomas Digges, in his Pantometria, described the various surveying instruments in use at that period, including a special type of theodolite, designed by his father, Leonard Digges, in which the sight-rule was mounted upon a graduated vertical semicircle which could rotate upon a vertical rod; the latter was in turn supported upon a horizontal ruler which could revolve over a graduated circle. This instrument thus foreshadowed the altazimuth theodolite, but it does not seem to have found much favour. About the same time, in 1590, Praetorius modified the ordinary plane-table by providing it with a clinometric sight-rule enabling altitude angles to be measured simultaneously with azimuths.

During the 17th century several auxiliary appliances were invented and incorporated in the design of angle-measuring instruments. Gallileo's telescope was not suited to surveying, but the invention of the Keplerian eyepiece transformed it into a sighting appliance far superior to the ordinary sight-rule. Gascoigne's invention about 1640 of the movable micrometer wire for the telescope eyepiece also added

to its convenience and precision. Picard appears to have been the first to apply, in 1666, the telescope to a surveying instrument. In 1631, Pierre Vernier devised the scale bearing his name, and thereby greatly facilitated the accurate determination of the position of the sight-rule with respect to the graduated scale. Verniers soon became necessary adjuncts of all accurate angle-measuring instruments. M. Thévenot invented the spirit level about 1661, but this useful appliance does not seem to have been utilized on surveying instruments until the commencement of the next century, when it rapidly superseded the plummet as a means for verticalizing the axes of theodolites.

When, at the beginning of the 18th century, telescopes began to supersede sight-rules on theodolites, the consequent restriction of the field of view necessitated a vertical as well as a horizontal motion of the telescope, and therefore the provision of a vertical graduated arc to measure this rotation. This century therefore witnessed the evolution of the altazimuth theodolite, in which a vertical graduated arc was fixed to the telescope and revolved with it between standards mounted upon the rotating horizontal vernier plate ; a compass was usually mounted upon this latter plate, and a bubble level was attached first to the telescope and later to the plate also. With such an instrument, azimuth angles and altitude angles were measured separately but simultaneously. For many purposes, however, where it was desired to measure an angle formed by rays from the station to two distant points, an instrument in which the plane of the graduated circle could be set so as to pass through the two distant points was obviously convenient. The reflecting sextant, developed by Newton and Hadley in the late 17th and early 18th centuries, fulfilled this purpose and presented the additional advantages that both distant points could be sighted simultaneously, and that the instrument could be held in the observer's hand. The reflecting circles of Tobias Mayer (1767) and Borda (1775) combined the reflecting principle of the sextant with the principle of the repetition of angles that had been propounded by the former. Such reflecting instruments found more favour on the continent than in England, where the altazimuth theodolite, as improved by Jonathan Sisson and Jesse Ramsden, became the standard instrument for the precise measurement of surveying angles. In minor surveys, the combination of the plain theodolite and compass known as the " circumferentor," without telescope, was commonly employed. With this instrument magnetic bearings could be quickly read off directly by means of the compass, whilst relative angular azimuths could be more precisely measured by the verniers on the divided limb of the theodolite.

During the latter half of the 18th century, the interest aroused by Newton's theory of gravitation combined with military exigencies to bring about a rapid succession of geodetic arc measurements and triangulation which called for terrestrial angular measurements of a precision not hitherto deemed necessary. In England, Ramsden constructed two large altazimuth theodolites (*see* No. 217) and many smaller ones for the projected trigonometrical survey of the country ; these instruments embodied all the recent improvements due to other inventors, and many due to Ramsden himself. He constructed a very accurate dividing machine for graduating the circles, devised special micrometer microscopes for increasing the precision with which the circles could be read, applied tangent clamps and slow motion screws

to enable the telescope to be correctly adjusted upon the distant point, and mounted all the movable parts upon well-designed and machined axes to ensure easy manipulation and accurate rotation.

In the 19th century, the tendency has been towards reducing the size of theodolites without decreasing their precision. The unceasing progress in the construction of optical and mechanical parts has enabled the desired accuracy of measurement to be attained with instruments having from 3 in. to 12 in. graduated circles, according to the precision required. The principal modifications in design have consisted in the adoption of the transit principle whereby the telescope can be completely revolved on its horizontal axis of rotation, even upon the smallest instruments, and the tendency to employ micrometer microscopes in preference to verniers whenever special accuracy of measurement is desired. The elaborate circular compass has been gradually replaced by a simple trough compass for occasionally orienting the theodolite, although, for precise work, no reliance is placed upon the magnetic needle owing to local attraction.

The telescopes of modern theodolites are usually provided with tacheometric diaphragms for the indirect measurement of distances, and, in recent years, with movable internal lenses for focussing. The circles are accurately graduated on silver by dividing machines, and the practice of enclosing these circles in dustproof cases is increasing.

FIXED ANGLE INSTRUMENTS.

133. PHOTOGRAPHS OF A CARVING OF A GROMA. Taken by the Municipal Museum, Ivrea, N. Italy.

Upon the tombstone of a Roman "Mensor," L. Aebutius Faustus, who lived about 100 A.D., is carved a crude representation of the "groma," or surveyor's cross, used by Roman surveyors to set out right angles. The photograph exhibited was taken from this tombstone, which is preserved in the Municipal Museum at Ivrea, North Italy.

The carving is a somewhat conventionalized perspective sketch, showing the two crossed arms of the "stella," with only two "pondera" (weights) instead of the four usually suspended, one from each end of the "stella." The "ferramentum," or staff, to support the "stella" is also depicted, passing through the intersection of the two arms of the latter.

In using such a groma, it would be set up so that one plummet hung over the station point, and one of the adjacent plummets lay in the direction from which the right angle was to be set off; a sight through the other adjacent plummet would then be taken from the station plummet.

(*See* Schöne, "Das Visirinstrument der römischen Feldmesser," Jahrb. d. Deutsch. Archäolog. Instituts, XVI, 1901, pp. 127–132.) Inv. 1923–492.

134. DRAWING OF A RESTORATION OF A SMALL GROMA.

Another example of the Roman groma, found near Eichstätt, Bavaria, has served as basis for Professor Schöne's reconstruction illustrated in this drawing. The groma discovered consisted of an iron "stella" mounted upon a "ferramentum," also of iron. The ends of the arms of the stella are bent and transfixed by iron bolts, which served to attach a square wooden frame—since perished—to the "stella," and to carry the plumb lines.

The length of each side of the wooden framework was 35 cm., and the height of the "ferramentum," exclusive of the upper and lower axis pins, is 35·5 cm. This instrument was, therefore, a small type of groma, and was probably mounted upon a wooden tripod, as shown in the drawing, so that the "stella" was at approximately the height of a man from the ground.

(*See* Schöne, "Das Visirinstrument der römischen Feldmesser," Jahrb. d. Deutsch. Archäolog. Instituts, XVI, 1901, pp. 127–132.) Inv. 1923–493.

135. REPRODUCTION OF A ROMAN GROMA. Made in the Museum. Plate III, Fig. 1, p. 56.

During excavations in the Via Abbonanza at Pompeii, in 1912, under the direction of Cav. M. Della Corte, fragments of a Roman groma were discovered. These fragments were sufficiently preserved and complete to enable Dr. Della Corte to reconstruct the original instrument with a certainty not hitherto attained owing to the meagre data available. The instrument exhibited has been constructed in accordance with the measurements and drawings supplied by Dr. Della Corte.

As previously reconstructed, the groma consisted of a cross, composed of two equal perpendicular arms intersecting at their centres, mounted upon a supporting staff (ferramentum), upon which the cross could revolve in azimuth; from the ends of the cross were suspended four plummets, through which sights were taken by the surveyor. This reconstruction comprises all the foregoing portions, with the additional modification that the cross is not supported directly upon the staff, but is pivoted upon the outer end of a curved bracket, which is in turn mounted rotatably upon the head of the staff. This arrangement enables the centre of the cross to be set above the mark on a boundary stone, whilst the staff is driven into the ground beside the stone; also, sights could be taken through opposite, not adjacent, plumb lines without interference from the staff.

The wooden staff, which is nearly 2 metres long, terminates at its lower end in a fluted iron shoe, and is encircled at its upper extremity by a brass collar, which forms a pivot for the curved bracket. This bracket is of wood, reinforced along its upper and lower faces by curved brass strips, and terminating at the staff end in a brass collar and at the cross end in a brass pivot upon which the cross is mounted. The horizontal distance between the cross and bracket pivot centres is 23·4 cm. The cross has a brass centre, and four tapered wooden arms, completely enclosed in thin iron sheeting and reinforced at their intersection by brass angle brackets. The bronze plummets are suspended through holes in the arms at distances of 45 cm. from the centre of the cross. Each plummet resembles its opposite in size and shape but differs from the neighbouring ones.

The actual portions discovered included all the metal parts, with a few traces of wood fibres embedded therein. The total height of the instrument is alone considered problematical.

(*See* M. Della Corte's article "Groma," in Monumenti Antichi, Accademia dei Lincei, Vol. XXVIII, 1922.) Inv. 1923–395, S.M. 1828.

136. CROSS STAFF. Made by Baldantoni, Ancona.

This instrument consists of a hollow brass sphere of 2½ in. diam., with vertical great circle sighting slits cut every 45° in its surface. It is used like the ordinary sight-rule cross staff for setting off angles of any multiple of 45°, and was probably made towards the end of the 17th century.

A socket fixed to the sphere serves to connect it to a stand. Inv. 1889–22.

137. CROSS STAFF. Made by Dollond.

This instrument, which was made in the late 18th or early 19th century, has two 6-in. brass sight rules fixed accurately at right angles to each other and a central screw thread for attaching it to a stand. Backsights and foresights can be taken through either rule, every vertical arm having both a slit backsight and a wire foresight. This type of instrument is mostly used in detail chain and offset surveying, for setting the offset rod at right angles to the chain.

Inv. 1921–81.

138. OPTICAL SQUARE. Presented by T. H. Court, Esq.

This instrument, made probably near the end of the 18th century, has two mirrors fixed to the base of a cylindrical brass box, with their planes at an angle of 45° to each other. One mirror is half unsilvered for direct vision, the other half and the whole of the second mirror being silvered, to reflect rays from objects at right angles to the line of vision. A circular aperture and rectangular windows are pierced in the side of the box opposite the mirrors. Inv. 1917–22.

139. OPTICAL OPPOSITE. Made by Adie, London. Presented by T. H. Court, Esq.

In this instrument, made in the middle of the 19th century, two right-angled reflecting prisms are mounted one upon the other, with their reflecting faces perpendicular.

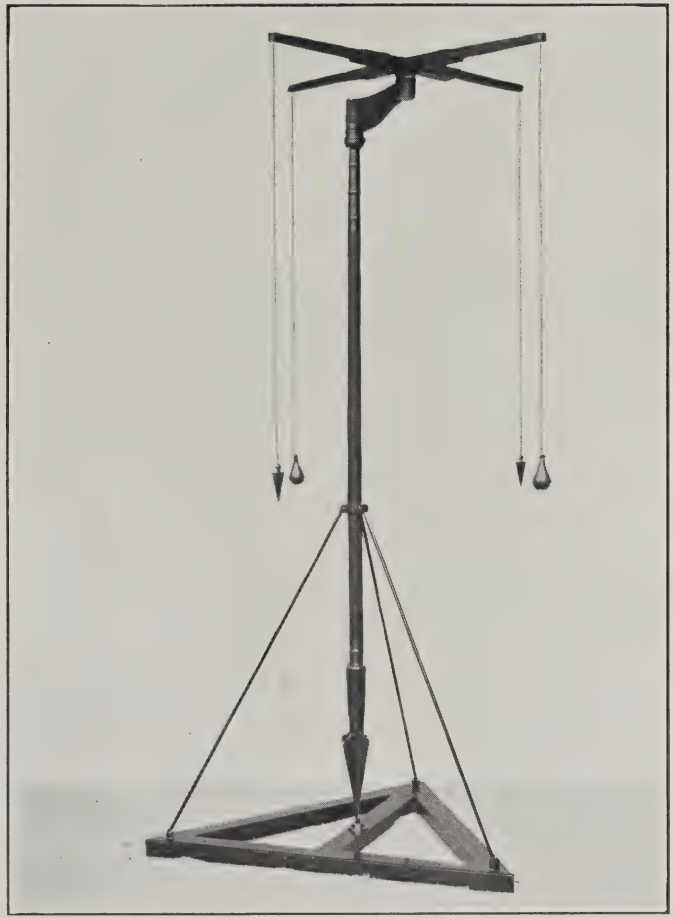

Fig. 1. Groma, p. 56.

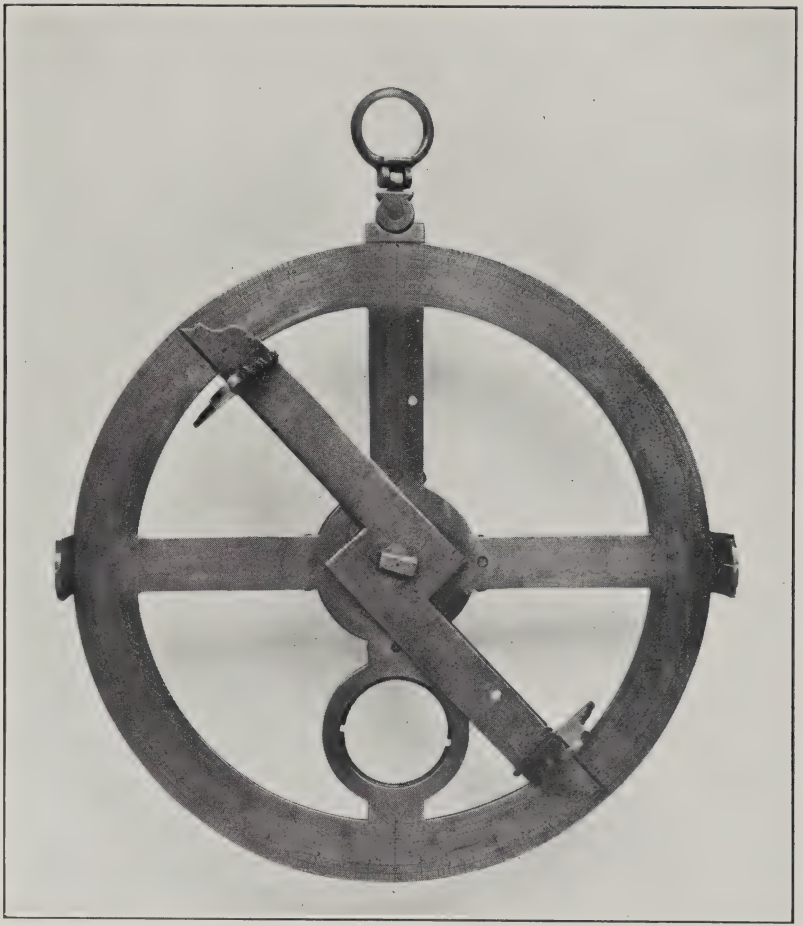

Fig. 2. Early Theodolite, p. 65.

In using the instrument the observer takes off the cap and screws it beneath the base to serve as a handgrip. Looking at the common face of the two prisms, he views objects on his left hand through the lower prism, and those on his right through the upper. Two objects which appear in the same vertical line will be at opposite ends of a line through the instrument, perpendicular to the direction of sight. Inv. 1911–152.

140. OPTICAL OPPOSITE AND SQUARE. Made by Beaulieu, Brussels. Presented by T. H. Court, Esq.

In this instrument, made probably towards the end of the 18th century, three pairs of mirrors are mounted successively in a rectangular brass box, whose sides are provided with the necessary windows. The three pairs of mirrors make angles of $22\frac{1}{2}°$, 90° and 45° respectively with each other, and one mirror of each pair is left partly unsilvered for direct vision. The direct and reflected rays for each pair are thus inclined at 45°, 180° and 90° respectively. Inv. 1911–154.

141. OPTICAL OPPOSITE. Presented by the Admiralty.

By means of this instrument an observer can place himself in the direct line between two objects. It consists of two mirrors set in small parallel sighting tubes connected by a longer perpendicular tube. The planes of the mirrors are perpendicular and one mirror is partly unsilvered. The observer views the front object directly through the unsilvered portion and the rear object by double reflection at the two silvered surfaces. When the images coincide, he is in the direct line between the two objects. The sighting tubes are closed by glass windows where necessary. Inv. 1876–1208.

PLANE TABLING.

142. TELESCOPIC PLANE TABLE ALIDADE. Made by A. Baldantoni, Ancona.

The application of the telescope and vertical arc to the alidade of a plane table took place about the same time as the corresponding addition to the theodolite.

In this exhibit, made in the late 17th century, a vertical pillar fixed perpendicularly to the alidade carries the vertical semicircle and attached telescope, which can rotate about a horizontal axis in the top of the pillar. A vernier fixed to the pillar records the altitude angle of the line of sight. The alidade is 2 ft. 4 in. long by $1\frac{3}{4}$ in. wide and has one edge bevelled. Over this edge, at the two extremities of the rule, are attached two plain sights, a slit backsight and a vertical wire foresight. A few inches in front of the backsight is the vertical pillar carrying the telescope axis. By means of its milled edge and a wormwheel, the socket of this pillar can be slightly rotated in azimuth, and carries the telescope with it. This serves to adjust the line of sight parallel to the bevelled edge of the rule. The semicircle has a diameter of 5 in. and is graduated in degrees up to 50° of elevation or depression. Its edge is milled and gears with a wormwheel attached to the pillar.

The telescope rests in semicircular collars fixed to the diameter of the semicircle, and is kept in place by hinged straps and screws. It has a rack-focussing objective lens of $\frac{3}{4}$ in. aperture and a fixed eyepiece tube containing a compound field lens and eyepiece with a fixed cross wire diaphragm between the two lenses of the eyepiece. A spirit level is mounted upon the telescope parallel to its axis. The vernier attached to the pillar is slightly adjustable by means of a slide and lever, and reads the vertical arc to 3 minutes. Inv. 1889–21.

143. PLANE TABLE AND ALIDADE. Made by W. & S. Jones. Lent by T. H. Court, Esq.

This is an early 19th century outfit comprising plane table, tripod and brass alidade. The table, which is 17 in. by 15 in. can be rotated and levelled independently of the tripod. The alidade is nearly 2 ft. long and has a detachable combined back and foresight at each extremity, the slits and wires being vertically above the bevelled edge of the ruler.

Various useful scales of length are engraved upon the alidade, and the rectangular boxwood frame forming the edge of the table is graduated on both faces in half degrees and tenth-inches. This frame is detachable and serves to clamp the paper to the table. Three centres corresponding to the half-degree graduations are marked on the table proper, by which means it can be used also as a theodolite. There is a dovetailed recess beneath the table for supporting a compass box (missing in the instrument exhibited) to orient the instrument, and a small spirit level is used to level the table. The brass piece connecting the table to the tripod has a conical axis and socket, and a spherical ball and socket joint for orienting and levelling the table independently of the tripod. The latter has a brass tripod head and circular tapering legs, 4 ft. long, jointed in the middle, and fitted with brass shoes at the extremities. Inv. 1917–106.

144. PLANE TABLE OUTFIT. Made by T. Cooke & Sons.

This is a small outfit of modern construction suitable for rough reconnaissance and engineering surveys. The table is 17 in. by 14 in. and has its under edges removable for inserting and clamping the drawing paper. The boxwood ruler is 12 in. long and has folding metal sights at each extremity.

The back of the table has a brass plate, recessed to receive the knob of the bolt clamping it to the tripod. A small circular spirit level is used to level the table, the slope of the tripod legs being changed to effect this. A small trough compass with a 3-in. needle is provided for orienting the table. The bevelled edges of the alidade are divided in scales of 6 and 8 inches to the mile, to read 10 yd. on each scale. The sights consist of a slit backsight and strip foresight, each vertically above the centre line of the alidade. Inv. 1899–52.

145. JOHNSON PLANE TABLE OUTFIT. Made by W. & L. E. Gurley.

A type of modern plane table outfit with telescopic alidade, suitable for topographical surveys of a comparatively high degree of precision, is here exhibited. Similar outfits have been extensively employed by the topographers of the U.S. Geological Survey.

The table is 30 in. by 24 in., and is carefully made in sections to preserve its shape. Brass screw pins fitting into sockets at the corners and middle of the sides are used for fastening the drawing paper to the table, which is slightly recessed at these points to allow the heads of the pins to be flush with the upper surface of the board and thus permit the alidade to slide freely over the pins.

The board is connected to the tripod by means of a Johnson quick-levelling socket, which permits it to be easily levelled and rotated in azimuth independently of the tripod. Two butterfly nuts control these movements of levelling and rotation, and, when tightened, clamp the table rigidly to the tripod. This latter has three split legs, 4 ft. long, attached by bolts to the metal tripod head and terminating in metal shoes.

Any point on the sketch can be set vertically above the corresponding station point, after the instrument is levelled, by means of the wooden plumbing arm which consists of two pieces so jointed and marked at the joint that, when the upper piece is set flat on the table, with its point over the point on the sketch, and the joint clamped with its two marks coincident, the metal hook at the end of the second arm lies vertically beneath the point. The plumb-bob is suspended from this hook and the table moved until it lies over the station point. A flat $4\frac{1}{2}$-in. square metal plate, upon which are mounted two mutually perpendicular spirit levels and a central compass box with a 3-in. needle and ring divided in degrees, is used for levelling and orienting the table.

The alidade consists of a flat brass ruler 20 in. long by 4 in. wide, having one edge bevelled and a central pillar projecting vertically from its upper face and supporting the telescope and attached vertical circle, and the fixed vernier for reading this latter. The vertical circle has a diameter of 4·5 in., and is divided on silver to half degrees, read by the vernier to single minutes. It is fixed with the telescope to the horizontal axis, which can rotate within a socket fixed to the vertical pillar. A tangent clamp and slow motion screw is fitted to this axis and connected to the vernier.

The telescope is of the pattern usually fixed to 5-in. transit theodolites. It has a rack-focussing objective lens of 1·2 in. aperture and 8 in. focal length, and a rack-focussing eyepiece magnifying 20 diameters. The fixed diaphragm has two horizontal stadia wires as well as the usual cross wires. Inv. 1914–742.

146. JÄHNS'S POLYMETER. Made by Schmidt & Hansch, Berlin.

The " Vielmesser " or Polymeter, invented by R. Jähns in 1873, is an early example of a plane table alidade adapted to measure the distance, altitude and azimuth of a point simultaneously. It is mounted upon a horizontal plane table, and used in conjunction with a tacheometric staff of constant interval, set vertically at the distant station.

The alidade consists of a T-shaped base piece, mounted on three levelling screws and provided with two spirit levels. A vertical arm projecting from the base piece carries two metal rulers, which can be rotated independently about a common horizontal axis in the vertical arm by means of quick and slow motion screws. The axis is perpendicular to the longer arm of the base piece, and there is a marking pin attached to the latter vertically beneath the axis, so that the alidade can be centred above the observing station point on the plan and rotated as a whole about this point. After this has been done, the inner edges of the two rulers are directed upon the upper and lower reference marks on the distant staff by means of a telescope fixed to the upper ruler. A vertical slide, which carries a distance piece and corresponding wooden scales, is then moved along the alidade until the distance piece—which can move up and down on the slide—fits accurately between the two rulers. There is a lever multiplying device to enable this adjustment to be made with extreme precision, and the final motion of the slide is performed with a slow motion screw. The marking pin attached to the slide vertically beneath the distance piece is now depressed, and the point so defined will correspond to the horizontal projection of the distant staff, both as regards azimuth and distance. The position of the distance piece on the wooden scale on the vertical slide gives the altitude of the staff. The scale of representation in each case is the ratio of the width of the distance piece to the staff interval. Five separate distance pieces are provided, with the corresponding wooden scales, so that a suitable scale of representation can be chosen. Inv. 1876–1200.

147. PRISMATIC ALIDADE. Made and lent by C. F. Casella & Co., Ltd.

In this alidade devised by the Rev. A. J. Potter for use with a plane table, the usual folding sights are replaced by a single right-angled prism which is mounted at one end of the ruler, with its reflecting base vertical and parallel to the edge of the latter. Any distant object can be viewed directly above the prism, whilst an image of the object can be seen through the prism after refraction on each face and reflection on the base. When the two images thus seen are made to coincide, the edge of the ruler must point at the distant object, and the direction line of the latter can be plotted.

The reflected image is inverted left for right compared with the direct image and is displaced laterally if the ruler is not sighted correctly so that coincidence is readily effected by adjusting the ruler.

The advantage of this type of alidade lies in the rigidity of the sights, absence of parallax with clearness of illumination, and the increased accuracy of alignment rendered possible by the fact that, for a given angular displacement of the ruler, the displacement of the reflected image is double that of the ruler.

The ruler is 15 in. long, and has its bevelled edge graduated in inches and tenths. A circular bubble level is mounted upon it near the prism.

Inv. 1924–466.

COMPASSES.

148. EARLY COMPASS.

This consists of a square brass plate with an engraved circle graduated in degrees over which moves an index arm carrying a small compass box. It dates from the 17th century and was probably used for plotting the bearings of objects taken with a circumferentor.

The side of the square plate is 3 in. long, as is also the diameter of the graduated circle. The compass box has a diameter of nearly 1 in. The N.–S. and E.–W. lines are engraved upon the base of the compass. When the needle is set over the N.–S. line, and the index arm which is always parallel to this line is set upon the graduation corresponding to the bearings, two sides of the square plate will be in the proper direction for plotting this bearing. The circle is divided into four quadrants and each quadrant is graduated from 0° to 90°, all the graduations beginning on the same line parallel to two sides of the plate.

Inv. 1880–198.

149. AZIMUTH COMPASS. Made by Dollond. Presented by T. H. Court, Esq.

This instrument, made by Dollond about 1770, is typical of the surveyor's compass previous to the invention of Kater's mirror compass or Schmalcalder's prismatic compass. Here the position of the needle upon the graduated compass ring, which is fixed, cannot be read at the same time as the object is viewed through the sights. Consequently it is necessary to use a stand to support the compass, and a socket is attached to the base of the wooden case for this purpose. The fixed compass ring is graduated in degrees continuously from 0° to 360° in a counter-clockwise direction. The slit backsight and wire foresight are fixed to the compass box at the 0° and 180° respectively. When the object is sighted, the reading of the S. end of the needle upon the graduated ring gives the correct magnetic bearing.

The compass ring is $4\frac{1}{2}$ in. diameter, and the sights are $6\frac{1}{2}$ in. apart. These latter can be folded down upon the face of the compass for transport, and a recess is provided in the lid of the wooden case for their reception. This lid, on being closed, depresses a pin which lifts the needle from its pivot and clamps it against the glass cover. Inv. 1912–243.

150. AZIMUTH COMPASS. Made by Adams.

This compass, probably made about the end of the 18th century, differs only in minor details from the adjacent one made by Dollond. It has a $3\frac{1}{4}$ in. compass ring graduated in degrees, mounted in a brass case to which sights can be fitted, and which has a threaded socket for attaching the instrument to a stand when taking bearings.

The graduations are numbered every 10° in quadrants, with the 0° at the N. and S. points. Opposite these points are sliding sockets in the outer case. The two sights, each having a slit and a wire for use as backsight and foresight respectively, are mounted in these sockets when in use, or fitted within the lid of the compass case for transport. The sights are 3 in. long. The compass needle is provided with a lifting lever actuated by a pin which is depressed when the lid is fitted on the case, but has no clamping arrangement. Inv. 1909–140.

151. MIRROR AZIMUTH COMPASS. Made by Thos. Jones. Lent by W. Shackleton, Esq., F.R.A.S.

The mirror attachment to the eye lens here shown was invented by Capt. Kater at the beginning of the 19th century, and enables the observer to view the graduations of the horizontal compass ring at the same time as he takes a sight. The compass ring is fixed to the rotating needle and is so graduated in half-degrees consecutively from 0° to 360° that correct bearings are read off immediately. The diameter of the compass card is $4\frac{1}{2}$ in.

The usual slit backsight and wire foresight are fixed to the compass box at a distance apart of 5 in. A small pin fixed in the case vertically beneath the backsight serves as fiducial mark, and its position on the graduated scale is seen through the mirror very clearly when the instrument is held about one foot away from the eye.

The foresight can be folded down upon the top of the case, and the compass card and needle are thereby automatically lifted from the pivot and clamped.

Inv. 1916–6. S.M. 962. L.S.

152. PRISMATIC COMPASS. Made by Schmalcalder.

The reflecting mirror used by Captain Kater for viewing the graduated compass ring was superseded in 1812 by the application of Schmalcalder's prismatic eyepiece to the compass. By this means the observer can read the bearing and sight the object simultaneously, and can thus dispense with a stand for the instrument. For this reason the prismatic compass has come into general use for rapid reconnaissance surveys. The example exhibited was constructed by Schmalcalder in the early part of the 19th century.

The compass card is $2\frac{1}{2}$ in. in diameter, and is fixed to the magnetic needle. It is graduated in consecutive half-degrees from 0° to 260° in a clockwise direction, the N. end of the needle being under the 180° mark. The diagonal prism is attached to the plate which has a slit serving as backsight, and is ground convex on one perpendicular face so as to magnify the image of the graduated card seen by reflection at its inclined face, which is silvered. This backsight plate is jointed

to the compass box, and can be folded down when the instrument is not in use. The foresight consists of a vertical wire fixed in a frame diametrically opposite the backsight, and similarly jointed to the base so as to fold down when not in use.

Mirrors and coloured glasses are attached to the sights for taking bearing upon the sun and other celestial objects. A lever is provided for lifting the needle from its pivot and locking the compass card when desired, and there is a steadying pin underneath the foresight for damping the oscillations of the card.

Inv. 1905–155.

153. TELESCOPIC PRISMATIC COMPASS. Made by Schmalcalder.

This instrument, constructed in the early part of the 19th century, is essentially a combined theodolite and prismatic compass. The telescopic alidade, which carries the prismatic eyepiece and a vernier underneath this, can be rotated about the vertical axis independently of the compass ring—the instrument thus acting as a theodolite—or can be rotated together with the compass ring, in which case it fulfils the functions of a prismatic compass. The compass ring is graduated directly to 20′ in a clockwise direction and is read by vernier to single minutes.

The instrument is attached to a stand by means of a ball and socket arrangement, and can be levelled independently of the stand by four screws which engage in threads in the socket and press against the vertical axis. There is also a tangent clamp and slow motion screw for rotating the whole instrument in azimuth, whilst a circular rack and pinion inside the compass box serves to rotate the alidade independently. This is actuated by the screw projecting beneath the compass. The telescope carries a small spirit level, and is screwed at the eyepiece end to a brass plate hinged to a sliding piece, whilst it rests at the objective end in a Y-piece fixed to another sliding piece. These two sliding pieces terminate at their lower ends in screws, which work in threaded plates screwed to the compass box. Thus the telescope can be elevated at either end with respect to the compass box and can be adjusted so as to be horizontal. It is focussed by sliding the objective lens.

Inv. 1911–180.

154. PRISMATIC COMPASS AND CLINOMETER. Made by Cary.

The quadrant attached to this instrument, which is in other respects similar to the Schmalcalder prismatic compass, enables it to be used for measuring altitudes as well as taking magnetic bearings. The quadrant has separate sights and a small spirit level fixed to a movable radial arm. A mark engraved on the outer end of this arm registers the altitude upon the graduated arc of the quadrant when the arm is horizontal and the sights are directed upon the distant object.

The compass ring is 2½ in. in diam. and is fixed to the rotating magnetic needle. It is graduated continuously in half-degrees from 0° to 360°. As the N. point of the needle is attached at the 180° mark of the ring, the correct bearing of the object sighted is read off directly through the prismatic eyepiece attached to the slit backsight. A small spirit level is fixed to the bottom of the case inside and serves to set the compass horizontal.

The altitude quadrant has a radius of 2 in. and is attached to the wire foresight of the compass. It is graduated in degrees from 0° to 90°, the radius corresponding to the former being parallel to the compass plane, and carrying the supplementary sights, a pin-hole backsight and a cross-wire foresight, for determining altitudes.

Mirrors and coloured glasses are attached to the two compass sights for taking bearings on high objects such as the sun. Inv. 1917–78.

155. PRISMATIC COMPASS. Made by Chamberlain.

In this instrument, constructed about the middle of the 19th century, the method of lifting and locking the compass card is similar to that employed by Schmalcalder. The card is graduated in degrees, in two sets numbered consecutively in the clockwise sense from 0° to 180°. There are no mirrors or coloured glasses for celestial observations.

The diameter of the compass ring is 2½ in. and it can be read by estimation to the nearest 10′. Inv. 1872–79.

156. PRISMATIC COMPASS. Lent by F. Newton & Co.

This instrument, which was made about the middle of the 19th century, differs very little from those made by Schmalcalder about 50 years previously. The compass card is not graduated continuously from 0° to 360°, but in two sets of 180°, both in the clockwise sense. It reads directly to half-degrees, and by estimation to 10′. The compass card is lifted and clamped by folding down the foresight.

The diameter of the compass ring is 3½ in. The usual mirror and coloured glasses are provided for observing celestial objects. The eye prism is adjustable for focussing, and there is a steadying pin under the foresight for damping the oscillations of the compass needle. Inv. 1865–7.

157. PRISMATIC COMPASS. Made by Cary, Porter, Ltd. Presented by the Admiralty.

Except for the arrangement to lift and lock the compass card, this instrument differs very little from those made by Schmalcalder nearly a century previously. The compass card, prismatic eyepiece, steadying pin, etc., remain the same, but the eyepiece is here arranged so that the eye must be nearer the slit for focussing than in Schmalcalder's instruments, whilst the folding down of the foresight upon the compass automatically lifts and clamps the card.

The compass card is 5 in. in diameter, and a duplicate card is provided. The card is graduated in half-degrees in the usual clockwise sense. Both the sights can be folded down, and the prismatic eyepiece can be adjusted for focussing the graduations. There are the usual mirrors and coloured glasses for taking bearings of celestial objects. A socket is rigidly fixed to the base of the compass box for attaching it to a stand. When the compass is so mounted, bearings can be taken to within 15′, and estimated to the nearest 5′. Inv. 1911–157.

158. PRISMATIC COMPASS (Mark VIII).

This is a modern type of compass specially designed for rough surveying and for night marching upon a given bearing, previously set off on the edge of the compass. It has a hair foresight upon the hinged lid, and a slit backsight upon the hinged mounting carrying the prismatic reader. Various marks in luminous paint upon the lid, cover plate and dial of the compass are used in night marching. The compass has a spring damping pin for checking the oscillations of the dial as well as a lifting pin for locking it when not in use.

The luminous marks on the lid are at the extremities of the hair foresight. The glass cover plate of the compass box has also a luminous mark and can be independently rotated so as to set this mark at any angle to the sight line. The angle so set is measured by means of an index mark on the cover in conjunction with the graduated edge of the compass box. This is set to the bearing upon which it is desired to march, and the cover plate locked by means of a spring catch which engages in the milled edge of the plate. The dial of the compass, which is fixed to the magnetic needle and pivoted so as to rotate freely, has a luminous arrow marked above the north pole of the magnet. When the compass is turned until the luminous mark on the cover plate lies above the luminous arrow on the dial, the luminous marks at the extremity of the hair line on the lid point in the direction it is desired to march.

For surveying purposes the compass dial is graduated in degrees round its edge, the numbers being inverted so as to appear upright when seen through the prism, and so arranged that the correct bearing of the line of sight is read directly through the prism. There is a supplementary set of numbered graduations every 5° for direct reading without using the prism. A ring is hinged to the box to steady it when taking bearings, and a lever on the lid automatically actuates the lifting pin when the lid is closed. The compass has a diameter of 2 in. Inv. 1922–41.

159. LIQUID PRISMATIC COMPASS. Made by Kelvin, Bottomley & Baird, Ltd.

This instrument combines the advantages of prismatic reading with the rapid and accurate setting afforded by nearly floating the compass card in a liquid, which reduces the friction of the pivot and rapidly damps the motion of the card. The dial can be illuminated for night reading by means of an electric bulb fixed beneath the transparent base of the compass box. A socket attached to the base enables the compass to be mounted upon the tripod exhibited with it.

The compass card has a diameter of 2·5 in. and is graduated in degrees, read by an internal index point mounted beneath the centre of the prismatic reader. The card carries two long cylindrical magnetic needles fixed below it with their axes parallel, and has a central buoyant chamber resting upon the pivot. The card, needles and pivot are enclosed in a watertight chamber filled with a mixture of water and alcohol, which has a low freezing point. The card just rests upon the pivot, without pressing much on it, so that there is little frictional resistance to its rotation, and its motion is nearly " critically damped " by the liquid so that it takes up its new setting after rotation within a few seconds. The prismatic

reader has a V-shaped backsight used with the long foresight bracket upon which is a travelling foresight. Owing to the freedom of the needle from vibration, the reading can be taken to the nearest fifth degree.

The electric bulb serving to illuminate the dial for night reading is operated by a plug switch and a battery of two small cells, carried in the leather case used for transporting the compass. Inv. 1922–44.

160. BURNIER'S COMBINED COMPASS AND CLINOMETER. Made by Bulbreck, Paris. Lent by T. H. Court, Esq.

In this type of military compass, invented by Capt. Burnier about 1850, the graduated edge of the compass ring, which is fixed to the needle and rotates with it, is perpendicular to the plane of the needle. The bearing of the sighting thread can therefore be viewed at the same time as a sight is taken.

A weighted disc is mounted parallel to the compass ring, and has a similar graduated edge. On clamping the compass ring and bringing the planes of both rings vertical, the disc is unclamped and serves as a clinometer. Either ring is viewed through a cylindrical eye lens, which closes the brass case and is about 2 cm. distant from the graduated edges.

A double-jointed socket attached to the base of the case permits the instrument to be rotated in a vertical or a horizontal plane upon a stick stand, and serves as a support for holding the instrument when no stand is used.

The compass ring is graduated in degrees continuously from 0° to 360°, and the magnetic bearing of the object sighted is read off directly. The clinometer ring is likewise graduated in degrees, and is weighted at the 90° portion. Each ring is 4 cm. diameter and has an edge 2 mm. deep.

The usual folding slit and wire sights are attached to the top of the case, and are easily viewed simultaneously with the graduated rings when the instrument is held about a foot from the eye. A wire mounted within the case near the graduated edges in the plane of these two sights serves as fiducial mark.

The whole instrument is compact and serviceable, and is in general use on the Continent for military and reconnaissance surveys.

(*See* Laussedat's " Recherches sur les Instruments Topographiques," Vol. I, p. 306.) Inv. 1916–64.

161. EXPERIMENTAL " POCKET ALTAZIMUTHS." Presented by C. F. Casella & Co., Ltd.

These two examples of Casella's " Pocket Altazimuth," or combined compass and clinometer, illustrate the experimental stages of development of the instrument, which is represented in its modern form by an adjacent exhibit.

Each instrument consists of two graduated aluminium rings separately mounted upon pivots along the axis of a single cylindrical metal box, which is closed by glass faces. A magnetic needle is fixed to one ring, which acts as a compass to determine azimuths, whilst the other ring is loaded at one point and serves as a plummet clinometer for measuring altitude angles. When not in use, each ring can be lifted from its pivots and clamped by means of a lever actuated by a sliding knob.

In one instrument the graduated edges of the rings are read by means of two small telescopes, one for each ring, mounted on the metal box ; a thin wire is stretched across the box between the telescopes and the rings and defines the index line, or line of sight. In the other instrument, a single telescope can be fitted so as to read either ring alternately, and also to sight upon a distant object. This telescope has a single objective lens and a dual eyepiece, comprising a lens for sighting on the distant object and a prism for reading the graduations upon the upper face of the compass or clinometer ring.

In both instruments the rings are graduated in degrees, and a flat footing is attached to the box so that it can be placed upon any surface of which the inclination is to be measured. Inv. 1923–414.

162. POCKET ALTAZIMUTH. Made by Casella.

This is a compact form of combined telescopic compass and clinometer of a design embodying improvements due to Sir Francis Galton, F.R.S. Either magnetic bearings or altitude angles can be measured independently, but not simultaneously, with it. It is particularly suitable for very approximate reconnaissance surveying.

It consists of two graduated rings, separately pivoted within a cylindrical case, having glass-covered ends parallel to the planes of the two rings. One of the rings is graduated at the 32 points of the compass, and has a diametrical magnetic needle whose centre rests on the pivot. The other ring is loaded at one part of its circumference and is pivoted to the case on each side. It is graduated in degrees, numbered in quadrants, with the zero point opposite the centre of gravity of the load. Both rings have a diameter of $1\frac{3}{4}$ in., the external diameter of the cylindrical case being $2\frac{1}{4}$ in. The compass ring only moves when its plane is horizontal, the clinometer ring when its plane is vertical. Each ring is clamped when the other is in use, and is read by the position of an index mark on the cylindrical case. The latter carries a telescope, whose axis is parallel to the ends of the cylinder and passes through the line of pivots of the ring. The telescope has its objective tube and eyepiece tube separately fixed to the case, the latter being partly without and partly within the case, and having a slide-focussing eyepiece. A hair line is stretched across the case just behind the objective lens. A base piece for supporting the instrument is attached to the case, with its plane base parallel to the axis of the telescope. There is also a central threaded hole in the case for fixing it to a tripod. A damping spring is provided for use with the compass ring. The complete instrument weighs only 8 oz.

Inv. 1893–148.

163. TELESCOPIC COMPASS.

This is a modern example of a French type of surveying compass, with an eccentrically mounted telescope, used on the Continent on minor work. The compass is fixed in a flat, rectangular wooden box, to one side of which is attached the telescope, rotating about an axis fixed perpendicularly to this side. The whole instrument can rotate in the plane of the compass ring, which can itself be varied by means of a ball-and-socket joint.

The instrument is attached to a " peg " stand by means of a brass socket connected to the compass by a ball-and-socket joint. By this means the compass can be set horizontal without adjusting the stand. The compass ring has a diameter of 5 in., and is graduated in half-degrees, numbered every 10° in the clockwise sense. The plane of rotation of the telescope is parallel to the 0° to 180° line of the ring. The telescope has a single fixed objective lens with a focal length of 6 in. The cross wires are also fixed, the single eye lens being slide focussing. A set-screw serves to clamp the socket to the tripod peg, and a clamping screw to prevent the horizontal rotation of the compass upon its platform. The ball-and-socket joint is fixed by means of a nut and bolt.

A small tube spirit level is mounted on one side of the compass box, and the compass needle can be elevated from its pivot by a locking lever.

Inv. 1919–416.

EARLY THEODOLITES.

164. EARLY CIRCUMFERENTOR. Lent by T. H. Court, Esq.

The date of this instrument is indicated by the allowance for magnetic declination on the compass ring, on which the meridian is engraved at the point 10° E. of N. This corresponds to the year 1590, in England.

It consists of a brass circle, $4\frac{1}{2}$ in. diam., having a small suspension ring, and a pair of fixed sights which define a horizontal line when the instrument is suspended from the ring. This circle acts as the base plate for a compass box, $3\frac{1}{2}$ in. diam., which has a separate graduated circle of 3 in. diam. The circular side of the compass box is movable about its centre, and carries a pair of sights, with pointers attached, the latter moving over the graduated circle on the base plate.

The instrument can be screwed on to a stick stand, for taking magnetic bearings in a horizontal plane, or suspended by the ring for taking altitude angles. In each case the movable sights are set along the line whose direction is required.

A lid is provided for protecting the instrument when it is not in use.

Inv. 1918–124.

165. EARLY THEODOLITE. Lent by T. H. Court, Esq.

This instrument probably dates from the early 17th century. It consists of a brass circle, 8 in. diam., graduated in degrees, having two pairs of fixed sights along perpendicular diameters, and a movable alidade fitted with pointers at each end. It can be set upon a stand for measuring angles in any plane, or suspended from a ring attached to the circumference for taking altitudes.

On the face of the circle is engraved a dial indicating the points of the compass, and a geometrical square with " Umbra Recta " and " Umbra Versa " scales, The circle is graduated continuously from 0° to 360°. Inv. 1918–123.

166. EARLY THEODOLITE. Lent by T. H. Court, Esq. Plate III, Fig. 2, p. 56.

In this instrument, which was probably made in the early 17th century, only one pair of fixed sights is provided, defining a horizontal line when the instrument is suspended from the ring attached to its circumference.

The diameter of the graduated circle is 10 in., and the movable alidade carries the usual slit sights and terminates in pointers. There is a circular ring on one arm of the instrument which probably supported a magnetic compass.

The circle is graduated in degrees in four sets from 0° to 90°. On the back of the instrument is attached a socket with a fixing screw for receiving the head of a stand. The suspension ring is specially jointed to permit the plane of the circle to hang freely vertical. Inv. 1918–126, S.M. 1856.

167. COMBINED GRAPHOMETER, SECTOR AND COMPASSES.

This instrument of Italian make was probably constructed in the late 16th or early 17th century, and consists of a graphometer whose alidades are fitted with points to serve as compasses, and have various scales engraved on them corresponding to those usually found on sectors, and used in measuring lines, setting off angles, taking weights of spherical shot, etc. A small magnetic compass is attached to the junction of the two alidades.

There is no evidence that this instrument was fitted to a stand, and it was presumably employed in conjunction with a plane table, on which it rested when angles were observed.

The semicircle is graduated in degrees, and is 6·5 in. in diam. The sights on the alidades are 8 in. apart. Inv. 1880–202.

168. IPODIMETER.

This is a 17th-century theodolite of Continental design, the alidade being mounted near the edge of the circle and connected to a centrally mounted parallel index arm used to read the circle. The circle has a diameter of 6¼ in., and a 2½-in. compass box is centrally fixed above the movable index arm.

The circle is divided on its outer edge into 360 degrees, but has a concentric circle, of 5 in. diam., divided into 320 parts, also read by the diametral index arm. Each circle is divided into octants and the divisions of each octant numbered in the clockwise sense from 0 to 45 on the outer circle and from 0 to 40 on the inner. The outer octants are successively designated by the letters T, G, L, S, O, A, P, M, which are the initial letters of the old Italian names for the compass points. The inner octants each commence at the central points of the outer ones, and are named Septentrio, Aquilo, Solanus, Eurus, Auster, Africus, Favonius, and Chaurus respectively, which are the old Latin titles for the winds corresponding to the cardinal points. The central index arm has bevelled edges at each extremity for reading the divisions. The alidade is about 9 in. long and has folding combined back and foresights at each end. It rotates with the index arm about the axis of the circle. The compass box, fixed to the circle above the index arm, has its base divided into octants, but no subdivisions. Inv. 1908–122.

169. GRAPHOMETER. Made by Christoff Kohler, Dresden, 1663.

This instrument is a combined graphometer, or surveying semicircle, and clinometer. The graduated semicircle can be detached from the frame and used as a protractor for plotting the angles in the field. A compass is attached to the frame for orienting the instrument, and the whole is attached to a stand by means of a double-knuckled joint, permitting it to be set in any plane. It can also rotate as a whole in that plane.

The semicircle has one fixed and one movable alidade, and is 5 in. in diam. It is graduated in degrees, and has a diagonal scale enabling it to read to 5′. This is particularly interesting as showing that the much simpler vernier system was not yet in general use, although invented over 30 years previously.

The compass ring has a diameter of 1½ in. and is graduated in degrees. On the back of the plate carrying it is a simple quadrant pendulum clinometer, also graduated in degrees, and provided with "Umbra Versa" and "Umbra Recta" scales for measuring heights.

The clinometer is attached to an alidade, which is connected to the semicircle by a spring clip and can be disconnected for taking altitudes.

Inv. 1894–106.

170. EARLY SURVEYING QUADRANT. Made by Lusuerg, Rome, 1674.

This instrument has a radius of 6 in. and is graduated in half-degrees. By means of a vernier arc covering 31° and divided into 60 parts, angles can be measured to the nearest half-minute. The index arm carrying this vernier is pivoted at the centre of the quadrant and carries three folding sights, one at its centre and the other two at the ends of its arc. Two similar sights are fixed at the ends of the quadrant arc. The quadrant is attached to a socket for fixing it upon a stand by a ball and socket joint permitting it to be set in any plane, including the vertical.

On the upper surface of the quadrant are engraved a tangent scale (" Scala altimetra "), concentric with the divided arc, and also linear scales and a rectangular network for use in plotting. On the lower surface is engraved a clinometer scale for artillery purposes and the arms and coronet of the Duke of Modena. The inscription " Jacobus Lusuerg Mutinensis Faciebat Romae A° 1674 ", engraved on the upper surface, gives the date and maker of the instrument. Inv. 1880–200.

171. EARLY THEODOLITE. Made by Joannes Macarius, Mirandola (Modena).

The date of construction, 1676, and maker's name are inscribed on this very fine example of an early theodolite, which has a circle of 12 in. diam., graduated every 10′ and read by a vernier on the alidade to 1′. A 2½-in. compass is fixed at the centre of the circle and has its ring divided in degrees.

The circle carries four fixed combined sights at the ends of mutually perpendicular diameters. Each sight has a vertical slit, a small aperture, and a pair of thin cross-pieces intersecting at the aperture and forming cross-wire foresights. The alidade, pivoted to rotate about the centre of the circle, has a similar pair of sights at the extremities of its index arm, and these have bevelled edges for reading the circle directly. The double vernier plate is screwed to the alidade at right angles to its direction of sight. Each vernier extends over 61° of the circle, and is divided into 60 parts. There are two vernier plates provided, the one fixed to the alidade having engraved upon it the various numbers of foreign feet equal to 1,000 Roman feet. The other vernier plate can be substituted for this one if required. The circle graduations have three sets of numbers, one consecutively from 0° to 360° in the clockwise sense, the other two by quadrants having the zero points beneath each of the fixed sights. Scales of sines, tangents and sides of inscribed polygons are also engraved on the circle, as well as various scales of length on its cross-bars. On the back of the circle are engraved other scales used in artillery and fortification work with the Latin inscription " Bonifacius March° Rangonus Faciedum jussit Mutinae Anno Domini, 1676 ".

A suspension shackle is fixed to the top of the circle for setting it in a vertical plane, and a socket is provided for mounting it horizontally upon a stand.
Inv. 1880–195.

172. GRAPHOMETER. Made by Deens, 1682.

This instrument consists of one fixed and one movable alidade, each provided with sights, intersecting each other at the centre of a semicircle graduated to read half-degrees. The whole is mounted upon a ball and socket joint, and can be used to measure angles in any plane.

In this instrument, no compass is attached for orientation, and the alidades are not provided with verniers. The graduated semicircle has a diameter of 11 cm., with two sets of supplementary figures.

An inscription on the movable alidade reads " Iodocus Deens Louaniensis Belga Austriorum Viennes fecit, 1682 ". Inv. 1892–9.

173. EARLY CIRCUMFERENTOR. Made by Lusuerg, Rome.

This example was constructed in 1686, and exhibits many characteristics of that period. The alidade plate is square, and can be detached from its support and employed as a protractor. On it are engraved three concentric graduated circles, of diameters 8 in., 7 in. and 3½ in. The outer circle is divided in degrees, with two sets of numberings. The central circle is a " Scala altimetra," or tangent scale, for measuring heights, and the inner circle is divided into 32 parts corresponding to the points of the compass. The movable alidade

Fig. 1. Circumferentor, by Thos. Wright, p. 67.

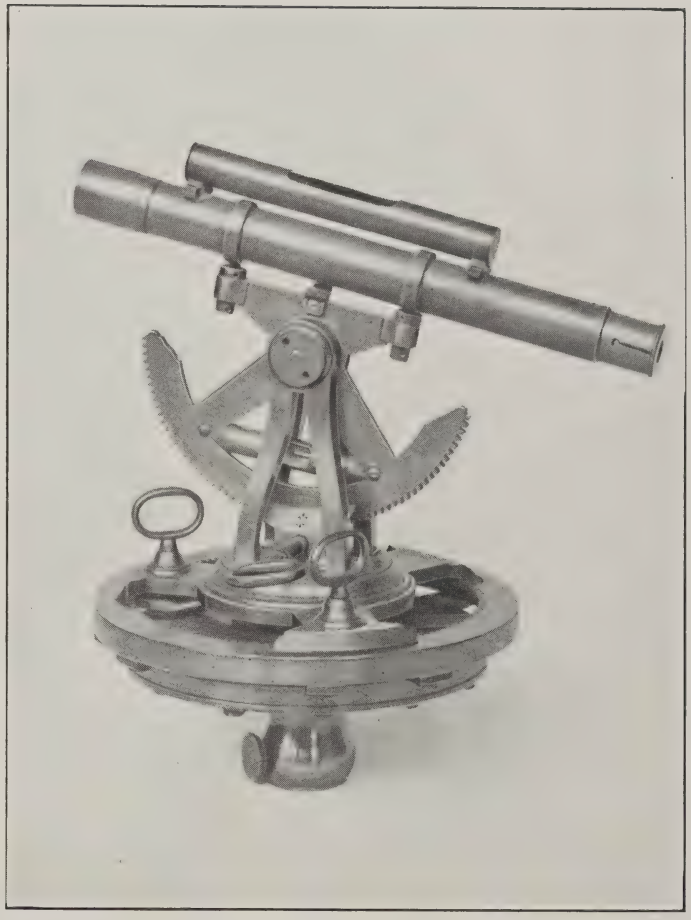

Fig. 2. Early Altazimuth Theodolite, by J. Sisson, p. 68.

carries a 2½-in. compass box, and is pivoted at the centre of the plate. At one end is a vernier arc which moves over the outer graduated circle, and reads this to single minutes, the 60 divisions of the vernier extending over 61°.

The fixed and movable sights have circular apertures, with vertical slits above their centres, and are carved and ornamentally engraved. Two edges of the square plate are parallel to the two fixed sights, which can be folded down upon the plate when not in use. The conical socket for attaching the instrument to its stand has a ball and socket joint permitting the alidade plate to be set in any plane, including the vertical. It is kept in position by the friction of the joint, there being no clamping screw.

The compass plate is graduated in degrees, numbered left and right from the N. and S. points from 0° to 90°. A compass rose indicating the 32 main points is engraved inside the circle. On the back of the alidade plate are engraved a clinometer scale for use of artillery, and the inscription "Jacobus Lusuerg Mutinensis Faciebat Romae A° 1686", with the arms and coronet of the Duke of Modena. Inv. 1880–199.

174. CIRCUMFERENTOR. Made by Thos. Wright. Plate IV, Fig. 1, p. 67.

This early 18th-century example is typical of the circumferentor of that period. It is a combined theodolite—having a graduated limb of 11 in. diam., reading by vernier to 5′—and compass, with a 6-in. needle reading to half-degrees.

The theodolite limb is graduated in single degrees in the clockwise sense from 0° to 360°, and carries a pair of fixed sights, each with a slit and window for sighting both ways, at its 0° and 180° marks. The movable alidade, carrying a similar pair of sights, has a vernier at one end reading to 5′ and a central fiducial mark at the other end. The compass box is fixed to this alidade with its N. point above the zero of the vernier. The compass ring is graduated consecutively in half-degrees from 0° to 360° in a counter-clockwise sense, so that the position of the N. end of the needle gives the magnetic bearing of the alidade sights.

Both pairs of sights are employed when the instrument is used as a theodolite, but only the alidade sights when taking magnetic bearings. The instrument is mounted upon a tripod when in use. Inv. 1914–561, S.M. 937, L.S.

175. CIRCUMFERENTOR. Made by J. Howard, London.

This early 18th-century instrument has a 10½-in. graduated circle, reading by vernier to 5′. The vernier is attached at one end of the movable alidade, to which is also fixed the compass ring, which has a 6-in. diam. and is graduated in degrees.

The sights on the movable alidade, and those fixed on the large circle are each fitted with both slits and vertical wires, and can be used either as back or fore sights. They are sufficiently high to permit the measurement of angles in the horizontal plane, and the whole instrument is designed for such measurements, and not for determining angles in any plane.

The outer circle is graduated in degrees, and reads from 0° to 360° in a clockwise sense. The fixed sights are attached at the 0° and 180° points. The compass ring has two sets of graduations, one set reading degrees from 0° to 360° in a counter-clockwise sense, the other set giving every 10° only from 0° to 90° in each quadrant, the N. and S. points being the zero points. The eight main points of the compass are likewise indicated.

The whole instrument fits upon a stand by means of a socket fixed on the back of the large circle. Inv. 1913–257.

176. GRAPHOMETER. Made by Macquart, Paris.

This is an early 18th-century example of the graphometer, or surveying semicircle, much used in France in preference to the English theodolite. It has a diameter of 11 in. and is graduated in degrees, read by vernier on the rotating alidade to 5′. A 3-in. compass, with its ring divided in degrees, is mounted eccentrically on the semicircle.

Combined slit and wire sights are fixed at opposite ends of the diameter of the semicircle, and their orientation determined by means of the compass. A similar pair of sights is attached to the alidade, which rotates about the centre of the semicircle, and has bevelled verniers at each end. The axis of the semicircle terminates below in a spherical ball and socket arrangement for mounting the instrument on a tripod and setting its semicircle in any plane.

The graduations of the semicircle are numbered both ways from 0° to 180°, those of the compass ring in four quadrants, with the zeros at the N. and S. points. The compass needle is supplied with a lifting needle for clamping it to the top of its box when transporting the instrument. Inv. 1908–118.

177. CIRCUMFERENTOR. Made by Baradelle, Paris.

In this instrument, which was constructed towards the end of the 18th century, the compass has a diameter of $1\frac{3}{4}$ in. and is graduated only at the eight cardinal points. It is arranged for a magnetic variation of 16° W.

The main circle has a diameter of 6 in. and is graduated in degrees, numbered both ways from 0° to 180° from the diameter underneath the pair of fixed sights. The alidade carrying the movable sights is fixed to the compass box and rotates with it about the vertical axis. The compass needle is pivoted upon a plate fixed to the horizontal circle. There are no verniers, but only bevelled reading edges, on the alidade, and the sights are not suited for sighting both ways, but consist of a simple slit backsight on one end of the alidade and a wire foresight at the other end. The graduated circle can be set in any desired plane by means of a ball and socket joint connecting it to the stand. Inv. 1908–119.

178. CIRCUMFERENTOR. Made by W. & S. Jones. Presented by Evan Roberts, Esq.

This instrument, made about the end of the 18th century, is a good example of the circumferentor of that period. It has two small spirit levels fixed in the base of the compass box for setting the instrument horizontal.

The 9-in. circle is graduated in degrees in the clockwise sense from 0° to 360°, and read by the vernier at one end of the alidade to 3′. The compass ring, with a 4-in. needle, is graduated in degrees in the counter-clockwise sense from 0° to 360°. Both fixed and movable sights are provided with slits and windows for sighting in either direction. The small spirit levels upon the base of the compass box were not considered necessary by the makers, but were provided owing to the wishes of many surveyors. The socket attached to the base does not appear to have the customary screw for clamping the instrument to its tripod.

(*See* Adams's " Geometrical and Graphical Essays," p. 213, and Plate XIV, Fig. 5.) Inv. 1912–308.

ALTAZIMUTH THEODOLITES.

179. EARLY ALTAZIMUTH THEODOLITE. Made by Thomas Wright. Presented by P. A. Newton, Esq.

This instrument, dating from the early part of the 18th century, illustrates a fundamental stage in the development of the theodolite. Upon the alidade of a " common theodolite " of the type very generally used in the 17th century, is mounted a fixed graduated vertical arc. A telescope upon which is fixed a longitudinal spirit level, carries a vernier arm which traverses the graduated arc as the telescope rotates, and thus measures the altitude of the object sighted at the same time as the alidade measures its azimuth.

The horizontal circle in this instrument has a diameter of 10 in. and is graduated in degrees, numbered from 0° to 260° in the clockwise sense. The alidade has a vernier at one extremity reading the horizontal circle to 5′. A 5-in. compass box is mounted centrally upon this alidade and gives magnetic bearings in single degrees. The vertical arc is graduated in degrees, with the zero at the point vertically beneath the telescope axis, and reads by vernier to 10′. Altitude angles up to 40° of elevation or depression can be measured.

The telescope has a focal length of 8 in., an aperture of 1 in., and an erecting eyepiece with a simple cross-wire diaphragm. The spirit level is rigidly attached to the telescope tube. The instrument is attached to its tripod by means of a socket fixed beneath the centre of the horizontal circle.

Inv. 1918–240. S.M. 1098. L.S.

180. EARLY ALTAZIMUTH THEODOLITE. Made by J. Sisson. Lent by T. H. Court, Esq. Plate IV, Fig. 2, p. 67.

Among the early 18th-century makers of surveying instruments, Sisson is generally regarded as the most expert, and his design of altazimuth theodolite, of which the instrument exhibited is typical, remained the standard until Ramsden's time. This example has a $4\frac{1}{2}$-in. horizontal circle, graduated in degrees and

read by three symmetrically placed verniers to 6′. The vertical arc, reading angles up to 70° of elevation or depression, has a radius of 2 in. and is similarly graduated and read by a single vernier centrally placed on the horizontal vernier plate.

Both circles have toothed edges, in which engage pinion wheels, the motion of rotation being effected by turning these pinions. The telescope is attached above the vertical arc by screw bearings which permit it to be adjusted to sight horizontally when the vertical arc reads zero. A small spirit level fixed above the telescope, and a smaller one rigidly joined to the vertical arc enable this adjustment to be effected. The horizontal axis of rotation of the vertical arc and telescope rests on standards projecting from the central plate carrying the three horizontal vernier arms. To one of these is attached a clamp and screw which regulates the friction between the movable vernier plate and the fixed horizontal circle. In another vernier arm is fixed the axis of rotation of the pinion wheel which engages in the teeth of the horizontal circle. Beneath the horizontal circle is screwed a compass box of 4 in. diameter. The compass ring is not graduated, but has index marks beneath the 0° and the 180° graduations of the horizontal circle. This enables the instrument to be oriented. The conical socket for attaching the theodolite to a staff, or to a levelling device consisting of two parallel plates and four levelling screws, is fixed beneath the compass box.

The telescope has a fixed objective of $\frac{1}{2}$-in. aperture, and a sliding Huygens ocular, with a simple fixed cross-wire diaphragm. Inv. 1921–588. S.M. 1858.

181. EARLY ALTAZIMUTH THEODOLITE. Made by Cole.

This instrument was probably constructed about 1760 and resembles the adjacent theodolite made by Wright. The vertical arc is fixed to the alidade, and the vernier to the telescope.

The 8-in. horizontal circle is graduated in degrees and read to 5′ by means of a vernier scale on the alidade. The vertical arc has a radius of 3 in. and is graduated in degrees up to 50° on each side of the zero. It also is read to 5′ by its vernier. The 4-in. compass mounted on the alidade is graduated in degrees in the counter clockwise sense.

The telescope of 10-in. focal length and 0·5-in. aperture, has a single lens, draw-focussing eyepiece and a simple cross-wire diaphragm. Spirit levels are fixed on the telescope tube and the base of the compass box. The two parallel plates for fixing the instrument to its tripod are connected by four levelling screws and a spherical joint. Inv. 1910–125.

182. ALTAZIMUTH THEODOLITE. Made by G. Adams. Lent by T. H. Court, Esq.

In this theodolite, made probably about 1770, the alidade is replaced by a circular plate carrying two widely separated standards upon which is mounted the horizontal axis of rotation. The vertical semicircle is fixed to this axis, whilst the vernier is fixed on the circular plate. The telescope rests in jointed rings attached above the semicircle.

The 7-in. horizontal circle is graduated in degrees, and read by a vernier scale on the alidade plate to 5′. The vertical semicircle is of the same diam. and is graduated in degrees on one side, with scales of feet and links on the other. It is also read by vernier to 5′, and can measure angles up to 60° on either side of the vertical. The compass fixed on the alidade plate has a diam. of 3 in. and is graduated in degrees.

The telescope, of 7-in. focal length and 0·5-in. aperture, has a single-lens, draw-focussing eyepiece. A spirit level is fixed by adjustable screws beneath the telescope tube, parallel to its axis.

The horizontal circle is attached by a clamping screw to the upper of two parallel plates, which are connected to each other by four levelling screws and a spherical joint. Inv. 1917–104. S.M. 950. L.S.

183. SMALL ALTAZIMUTH THEODOLITE. Made by G. Adams. Lent by the Royal Society.

In its essential features this theodolite is a smaller example of the adjacent type by the same maker. A supplementary telescope is fixed to the horizontal circle for keeping the back station in view, whilst both the vertical arc and horizontal circle have milled edges and are rotated by small pinions gearing with the edges. The base of the horizontal circle forms the upper parallel plate for levelling.

The 5-in. horizontal circle and 3·5-in. vertical arc are graduated in degrees, and read by verniers to 5′. Angles up to 65° on either side of the vertical can be taken. The telescope has a 4·5-in. objective, with an aperture of 0·3 in. and a simple cross-wire diaphragm. It has a small magnification—about 2 diam.—and no focussing arrangement. The supplementary telescope is of similar construction and dimensions. A small spirit level is fixed in adjustable bearings beneath the main telescope parallel to its optical axis. The telescope rests in Y-s, fixed to the ends of the vertical semicircle, and is kept in position by retaining straps. The bracket supporting the axis of rotation of the vertical arc carries the vernier and is supported on the alidade above the compass box. This latter has a compass ring of 3-in. diam., graduated in degrees. The needle is missing.

The lower parallel plate is attached to the base of the horizontal circle by a ball and socket joint, and carries a conical socket with a clamping spring and screw for mounting the instrument on the peg of a tripod.

On the back of the vertical circle are graduated scales of feet and links, the former being a tangent series and the latter one of hypotenusal increments.

Inv. 1900–153. S.M. 938. L.S.

184. ALTAZIMUTH THEODOLITE. Made by Ramsden. Lent by T. H. Court, Esq.

This instrument, made towards the end of the 18th century, illustrates the many improvements in design due to Ramsden. The alidade and horizontal plates have their graduated edges bevelled to facilitate reading, and are supported by accurately made conical axes. A tangent clamp and slow-motion screw control the horizontal motion, and the ball and socket joint connecting the two parallel plates of the levelling attachment is very solidly and accurately constructed.

The telescope has an achromatic, rack-focussing objective lens of 8·5-in. focal length and 1-in. aperture, and an erecting eyepiece. It rests in Y-s attached to the ends of the vertical semicircle, which has a radius of 3 in. and is graduated on one face in half-degrees. This arc is read by a fixed vernier to 1′, and can measure angles of elevation or depression up to 60°.

The 7-in. horizontal circle is divided in half-degrees and read by two opposing verniers to 1′. The compass box, has a 3-in. ring graduated in degrees and a sensitive needle which can be lifted from its pivot by means of a lever when required. The box is mounted between the telescope standards upon an adjustable stage, which is connected to the horizontal vernier plate by capstan-headed screws.

Spirit levels are mounted on the telescope and the vernier plate.

Inv. 1913–571.

185. ALTAZIMUTH THEODOLITE. Made by Troughton.

This instrument was made in the early part of the 19th century, and in details resembles the adjacent example made by Ramsden. There is, however, a supplementary telescope used for keeping the back-set station in view.

The horizontal circle and vertical semicircle have diameters of 7 in., are graduated in half-degrees, and read by vernier to single minutes. Both are rotated by rack and pinion movements. There is a tangent clamp and slow-motion screw to the horizontal circle. The telescope rests in Y-s attached to the vertical arc, and moves with this. The standards supporting the horizontal axis of rotation are fixed upon an adjustable stage, attached to the alidade plate by three capstan-headed screws. This stage carries the compass box, which has a 3¼-in. ring, graduated in degrees. The two telescopes are of precisely similar optical construction. Each has a 7-in. achromatic objective, with a 1·2-in. aperture, and a rack and pinion-focussing mechanism. Their eyepieces are erecting and consist of four lenses, with a draw-focussing mechanism. The supplementary telescope has a full azimuthal motion round the vertical axis of the instrument, and a small altitude movement. The construction of the parallel plate mounting is of the usual Ramsden type, with four levelling screws. There is a longitudinal spirit level fixed in adjustable bearings beneath the telescope, and two levels with their axes at right angles on the alidade plate. Inv. 1909–138.

186. ALTAZIMUTH THEODOLITE. Made by W. Harris.

This instrument, although made in the middle of the 19th century, retains most of the features characterising the Ramsden type of theodolite. Tangent clamps and slow-motion screws replace the Ramsden rack and pinion movements

for both horizontal and vertical circles, and small reading microscopes are provided near the verniers. The supporting standards for the horizontal axis of rotation are not mounted upon an adjustable stage, as in Ramsden's instruments, but are fixed directly to the alidade plate.

The horizontal circle has a diameter of 6 in. and the vertical semicircle one of $5\frac{1}{2}$ in. Both are graduated in half-degrees and read by vernier to 1′. The telescope is mounted in Y-s attached to the vertical arc. It has a 9-in. achromatic objective, with a 1-in. aperture and a rack-focussing arrangement. The eyepiece is erecting, with four lenses, and a draw-focussing mechanism. The diaphragm has one vertical and one horizontal wire. A sensitive longitudinal spirit level is fixed in adjustable bearings beneath the telescope. On the alidade there are two smaller levels at right angles to each other, and a 3-in. compass graduated in degrees. The parallel plates are of the usual Ramsden type, with four levelling screws. Inv. 1872–80.

187. ALTAZIMUTH THEODOLITE. Made by W. & T. Gilbert, London. Lent by T. H. Court, Esq.

This instrument, probably constructed about 1840, differs in many respects from the more usual Y-theodolite of the period. Its telescope is rigidly attached to the horizontal axis of rotation, which carries the vertical arc and rests in bearings upon two standards fixed to the rim of a case whose bottom forms the alidade. This case is closed at the top by a glass cover, so that the horizontal circle and compass are enclosed. Reading microscopes with prism reflectors are attached to the case for reading the verniers of the horizontal circle. Tangent clamps and slow-motion screws are fitted to both circles. The upper part of the instrument is suspended in a gimbal mounting within a hollow cylinder screwed upon the tripod plate, and can be levelled independently of the tripod by two screws threaded into the cylinder, with diametrically opposite springs. These screws press against a square nut fixed to the lower end of the axial cone which carries the horizontal circle.

The 6-in. horizontal circle is graduated to 20′, and read by vernier to 30′. The 5-in. vertical arc is similarly graduated and read by vernier, and has a range of 50° on either side of the zero mark. The telescope is achromatic, with a 1-in. aperture and 8-in. focal length. The objective is focussed by a rack and pinion mechanism. The eyepiece is a simple Ramsden inverting draw-focussing one, and the diaphragm has one vertical and one horizontal wire. A diagonal reflecting mirror can be attached in front of the objective for taking steep sights. There is one longitudinal adjustable spirit level attached beneath the telescope, and a parallel one fixed to the standards but no transverse level. The alidade carries a 3-in. compass, graduated in degrees. Inv. 1914–894.

188. ALTAZIMUTH THEODOLITE (Everest Type). Made by T. Cooke & Sons. Presented by the Ordnance Survey.

The Everest pattern theodolite, although not possessing the advantage of a transit instrument, has been much used by the British and Indian Survey departments since its inception, due to Sir George (then Captain) Everest, about the year 1835. The one exhibited is a late 19th-century 5-in. model, the horizontal circle and vertical arcs being graduated to 20′ and read by two opposing verniers to 30″.

In the Everest type of theodolite two opposing vertical arcs are used instead of a complete vertical circle, and the horizontal axis to which the telescope and arcs are fixed, is mounted upon two short standards projecting from a central pillar, supported on the horizontal vernier plate. The vernier bracket and attached spirit level are mounted on the axis, and are clamped to one standard by opposing screws. Two perpendicular spirit levels are likewise mounted on the horizontal vernier plate. The horizontal circle has a bevelled graduated edge and a separate mounting on the vertical axis cone. Thus the vernier plate and circle have independent motions, controlled by clamps and tangent screws, for repeating azimuth angles. All verniers are provided with reading microscopes. The instrument has a tribrach mounting, the feet of the three levelling screws resting in grooves in a trivet plate and being locked therein by a spring-controlled locking plate—also a feature of the original Everest design.

The telescope has a rack-focussing objective of 1·2-in. aperture and 9-in. focal length, and a slide-focussing Ramsden eyepiece.

Owing to the low standards, angles of elevation beyond 30° and of depression beyond 45° cannot be measured, as the telescope then fouls the horizontal plates. The vertical arcs consequently only extend about 50° on each side of the horizontal zeros. Inv. 1895–49.

189. TRANSIT THEODOLITE. Made by Troughton & Simms.

The introduction of the transit principle into medium and small-sized theodolites in England took place in the early part of the 19th century. This exhibit is an early example of such a theodolite. Below the horizontal circle it resembles Ramsden's Y-theodolite, but the upper part has standards sufficiently high to permit the telescope to transit at either end. Both horizontal and vertical circles are 6 in. diam., divided on silver to 10′ and read by opposing verniers to 10″.

The vernier plate and horizontal circle have independent axes of rotation for repeating angles, and are bevelled at the graduations to facilitate reading. Reading microscopes are provided for both circles, and also tangent clamps and slow-motion screws, as well as a similar clamp and screw connecting the vernier plate to the horizontal circle. The axis of this circle rests in a conical socket attached to the upper of two parallel levelling plates, connected by four screws and a ball and socket joint. The vernier plate carries a single spirit level, parallel to the transit axis, and a central circular compass box, with a 3½-in. stepped ring graduated in degrees. The needle, of rectangular section with its longer side vertical, is provided with a lifting lever for clamping it. The vertical circle is attached to the telescope and transit axis, and is read by horizontal verniers on a bracket fixed to one standard. This bracket carries the clamp and tangent screw. The other standard carries a spirit level perpendicular to the transit axis. The telescope, fixed in the centre of the transit axis, has a rack-focussing objective of 1·5-in. aperture and 10-in. focal length, a fixed diaphragm having one vertical and three equidistant horizontal wires, and a slide-focussing Ramsden eyepiece. A sensitive spirit level is mounted parallel to the axis of the telescope.

Inv. 1909–137.

190. TRANSIT THEODOLITE. Made by Thos. Jones. Presented by the Admiralty.

In this instrument, made in the early part of the 19th century, the 8½-in. horizontal and the 7½-in. vertical circles are graduated every 10′ and read by vernier to 10″. The vertical circle and telescope are rigidly joined to the transit axis, and rotate with it, the verniers being fixed to one standard. The horizontal circle and vernier plate can rotate independently about the vertical axis, for repeating azimuth angles.

The three footscrews for levelling the instrument are fixed to the base circle of a framed stand having a central conical socket, into which fits the hollow conical axis attached beneath the horizontal circle. The axis of the vernier plate fits within this and is kept in position by a screw and washer fitted in its lower end and abutting against the socket in the stand. The vernier plate carries three symmetrically placed vernier arms, with reading microscopes suspended above their verniers, and is provided with a sensitive spirit level, with its axis perpendicular to the transit axis. The standards supporting the transit axis project from the vernier plate, and have Y-s at their upper ends, one of which is adjustable. The axis is kept in position in these Y-s by metal straps ; it is hollow, and permits the telescope to be illuminated by means of a lamp supported by a bracket fixed to one standard. The vernier bracket for reading the vertical circle carries a spirit level parallel to its two vernier arms, for setting their zeros horizontal. It has a projecting piece which fits between screws fixed to the standard, and keeps the verniers stationary when the telescope and circle rotate. The telescope has a fixed objective of 11-in. focal length and 1·8-in. clear aperture, and a central mirror for illuminating the axis at night. The eyepiece tube can be focussed by a rack and pinion mechanism, and carries the diaphragm, having five vertical and one horizontal threads, and the inverting, draw-focussing eyepiece, which fits in a slide permitting a slight lateral motion of the eyepiece.

Clamps and tangent screws for fine motion are fitted to both circles and the horizontal vernier plate. Inv. 1876–1206.

191. TRANSIT THEODOLITE. Made by Cary. Presented by the Admiralty.

This is an early 19th-century example of a medium-sized transit theodolite. The 10-in. vertical and horizontal circles are graduated on silver every 10′, and read by two opposing verniers to 10″ of arc. The telescope transits at the eyepiece end, and its axis can be illuminated for night reading through the hollow horizontal axis of rotation. The instrument is mounted upon a tribrach having three footscrews for levelling ; these rest upon a plate screwed to the tripod head and are kept in position by a locking plate of the Everest pattern.

The horizontal circle can rotate freely about the vertical axis, or can be clamped to it and rotated slowly by means of a tangent screw. The vernier plate can be similarly clamped to the horizontal circle, or rotated freely. Reading microscopes are fixed on brackets above each vernier. An adjustable spirit level is fixed to the vernier plate, perpendicular to the line joining the two standards which support the vertical circle and telescope. The vertical circle is mounted upon the axis of rotation of the telescope, and is read by verniers at the ends of a bracket fixed to one standard. Reading microscopes are attached to this bracket for use with each vernier, and a spirit level is mounted in adjustable bearings on the bracket with its axis parallel to the line joining the vernier zeros. A tangent clamp and slow-motion screw connects the vertical circle to one standard. Upon the top of the telescope, parallel to its axis, is set a 7-in. trough compass. The lamp for illuminating the telescope axis rests upon a bracket fixed to one standard, with its lens opposite the end of the horizontal axis of rotation. A mirror in the centre of the telescope reflects the light down its axis.

The telescope has an achromatic objective of 1·5-in. aperture and 15-in. focal length. Three eyepieces are provided, one inverting, one erecting, and one diagonal for taking steep sights. There is a sensitive striding level for testing the horizontal axis, one of the trunnions being adjustable on its standard. A plumb-bob for centring the instrument over a station point is also provided.

Inv. 1911–160.

192. TRANSIT THEODOLITE. Made by Robinson, London. Presented by the Admiralty.

This example of a 5-in. transit theodolite was probably constructed about 1850. Both horizontal and vertical circles are graduated in half-degrees and read by vernier to single minutes. A trough compass is fixed above the telescope instead of the spirit-level more usually found in the Ramsden type of altazimuth. The footscrews of the tribrach are designed to be inserted in a locking plate attached to the tripod, from which the vertical axis of the instrument is completely separated.

The vernier plate for the horizontal circle carries two spirit levels with their axes mutually perpendicular, and has three symmetrically disposed verniers, with small reading microscopes suspended above them. A tangent clamp and slow-motion screw mechanism is fixed to this plate to clamp it to the horizontal circle. This latter can rotate independently about the vertical axis, or can be clamped to it by means of a tangent screw attached to the tribrach. The standards supporting the upper part are fixed rigidly to the vernier plate. The horizontal axis rests in bearings on these standards, and is retained in position by metal straps. This axis carries the telescope and two vertical circles, one on each side of the telescope. Only one of these is graduated, and is read by means of two verniers on a bracket mounted upon the axis, but fixed to one standard. Two reading lenses are mounted on a movable arm for use with these verniers. To the other standard is fixed a tangent clamp and slow-motion screw arrangement for fixing the vertical circles and telescope. The trough compass box is 5 in. long, and rests upon the distance pieces which connect the two circles, parallel to the telescope. The needle can be raised from its pivot and clamped when required.

A striding level is provided for testing the horizontality of the axis of rotation.

The telescope has an objective of 1-in. aperture and 8-in. focal length. The diaphragm is fixed in the eyepiece tube, which is focussed by a rack and pinion mechanism. There are three vertical and one horizontal wires. A diagonal erecting eyepiece is provided in addition to the normal inverting one. The telescope transits at the eyepiece end. Inv. 1911–159.

193. TRANSIT THEODOLITE. Made by Henry Barrow & Co. Presented by the Admiralty.

This instrument, made in the middle of the 19th century, has 6-in. vertical and horizontal circles, very finely graduated on silver to 10′ of arc, and reading by vernier and microscopes to 10″. In general construction, it resembles rather a Borda repeating circle than an English theodolite, the whole upper part being supported by a single central pillar, so that the telescope is slightly eccentric and needs a counterpoise. Both the vertical and horizontal circles can rotate independently of their verniers, so that angles can be " repeated " on both circles.

Three symmetrically disposed verniers for reading the horizontal circle are attached to a light frame to which the central pillar is fixed. Reading microscopes are suspended above each vernier, and a tangent clamp and screw-fitting permits the vernier bracket to be clamped to the horizontal circle, which can

itself be clamped to the vertical axis by a tangent screw. There are two verniers, with reading microscopes, rigidly attached to the telescope. Upon the same axis, but capable of independent rotation, are the vertical circle and a counterpoise circle; the axis also carries a spirit level fixed horizontally on adjustable bearings. The vertical circle is clamped by a screw attached to the counterpoise, a slow-motion screw being provided. A similar clamp and screw connect the vertical circle and the vernier bracket.

The telescope has a rack-focussing objective of aperture 1·1 in. and focal length 9·5 in. The diaphragm is fixed in the telescope tube and has two wires forming an acute angled cross instead of the usual vertical wire, together with a single horizontal wire. Three eyepieces are provided, all inverting; one is diagonal for taking steep sights, whilst the other two have different magnifications. The instrument has a tribrach mounting, with three footscrews set in a locking plate of the Everest pattern. The telescope transits at the objective end. A supplementary telescope is provided and can be fixed near the edge of the horizontal circle. It is of equal dimensions with the main telescope, and is used for keeping the back-set station in view, and also as a test of the fixity of the horizontal circle when the upper part is rotated. Inv. 1911–158.

194. TRAVELLER'S THEODOLITE. Made by Robinson, London. Lent by T. H. Court, Esq.

This is a highly compact transit theodolite, with vertical and horizontal circles of diameter 3·5 in., graduated in half-degrees and read by vernier to single minutes. It rests on three levelling screws, which can be fitted within three V-shaped notches in the top of the case. The instrument was probably constructed in the middle of the 19th century.

The horizontal circle is fixed to the tribrach, which carries a supplementary telescope, tangential to the circle, for keeping the back station in view. A single central standard projects vertically from the horizontal circle, and serves as axis for the hollow cylinder which carries the vernier bracket for the horizontal circle at its lower extremity, and a bracket to which is fixed the vertical circle at its upper end. The telescope is fixed to an arm carrying opposing verniers for the vertical circle, and can rotate with this arm about a horizontal axis through the top of the standard. A spirit level is attached to the back of the vertical circle, at right angles to the standard. Tangent clamps and slow-motion screws are fixed to the vernier brackets of both circles, and there are magnifying lenses for facilitating the reading of the vernier. There are three verniers to the horizontal circle, symmetrically disposed round its circumference. The vertical circle has two verniers at opposite ends of a diameter. The main and supplementary telescopes are of equal size and power. Their objectives have a focal length of 3·5 in., and a clear aperture of 0·6 in. They slide in the telescope tubes for focussing. The eyepieces are of the Ramsden type. Diaphragms fitted with cross wires are fixed inside the telescope tubes. The one on the main telescope has two vertical wires and one horizontal wire. A diagonal eyepiece is provided for taking steep sights. As the telescope is slightly eccentric to the vertical standard, a counterpoise to balance its weight is fitted on the standard. Inv. 1917–105.

195. TRANSIT THEODOLITE. Made by O. Fennel, Cassel.

The horizontal circle in this instrument, which was made about 1875, has a separate axis with clamps and tangent screw for repeating angles, and is covered by a metal plate attached to the vernier plate. It has a diameter of 14 cm. and is graduated every 20′ and read by opposing verniers and reading microscopes to 20″. The reversible level fixed to the telescope has its upper and lower faces graduated, and can be used before and after this is transited. The circular metal footplates attached to the extremities of the footscrews by ball and socket joints are peculiar to German instruments. They allow the theodolite to be moved over the surface of the tripod head for centring, which movement is permitted by the special arrangement for connecting the instrument and tripod.

The vertical circle has a diameter of 12 cm. and is graduated in half-degrees and read by a single vernier to minutes. It is rigidly fixed to the transit axis and telescope. This has a fixed objective of 22-cm. focal length and 3-cm. aperture, and a rack-focussing eyepiece tube, carrying the fixed diaphragm and a slide-focussing inverting eyepiece. The reversible level is attached by adjustable screws parallel to the axis of the telescope. Any error in adjustment between the level and telescope is automatically corrected by transiting the telescope and again levelling it after rotation horizontally through 180°. An axis clamp and

tangent screw for fine vertical motion is attached to one standard, the Y-bearing of this being adjustable vertically. The axis is kept in the bearings by metal straps. Between the standards is a small circular spirit level, for roughly setting the plate horizontal, the final levelling being tested by the spirit level attached to the telescope. The vernier plate has a clamp and tangent screw in addition to that on the horizontal circle. The instrument has a tribrach mounting, with three levelling screws, and is connected to the tripod head by a central screw and spring. On loosening this the theodolite can be moved laterally for centring above the station point. Inv. 1876–1193.

196. TRANSIT THEODOLITE. Made by A. & R. Hahn, Cassel.

This is a repeating theodolite, made about 1875, and resembles the adjacent one by Fennel in general construction. It differs, however, in having an ordinary, one-sided spirit level attached to the telescope, which has also a Huygens, not a Ramsden, eyepiece. The horizontal circle has a diameter of 14 cm., is graduated every 20′ and read by two opposing verniers and reading microscopes to 30″. The vertical circle, of 10·5 cm. diam., is divided to 30′ and read by opposing verniers to single minutes.

The telescope has a fixed objective, of 2·5-cm. clear aperture and, with the field lens of the eyepiece, a focal length of 23 cm. The eyepiece is focussed by a rack and pinion arrangement, the cross-wire diaphragm being fixed between the two lenses. The telescope, rigidly attached to the horizontal axis and vertical circle, transits at the eyepiece end, and has a sensitive longitudinal spirit level mounted on it in adjustable bearings. The vertical vernier bracket is screwed to one standard, whilst the other carries the tangent screw and clamping spring for the transit axis. The horizontal vernier plate carries a metal cover which protects the horizontal circle and supports the standards, a central circular spirit level, and the reading microscopes. There are windows in this plate above the verniers, and reflectors are attached to the microscopes for illuminating the field. The horizontal circle has a separate axis, with clamp and tangent screw for repetition. This fits in the socket fixed to the tribrach, which has three levelling screws furnished at their feet with small metal plates, to which they are connected by ball and socket joints. The instrument is connected to its tripod by the usual German central screw, with a flange and opposing spring which fix the instrument tightly, but on loosening the screw permit the theodolite to be displaced laterally for accurate centring over the station point. Inv. 1876–1192.

197. TRANSIT THEODOLITE. Made by Dennert & Pape, Altona.

The horizontal circle and vernier plate in this instrument, which was constructed about 1875, have independent motions about the vertical axis, for repeating azimuth angles. Clamps and tangent screws are provided for both circles, and for the vertical circle. The horizontal and vertical circles have diameters 21 and 13 cm. respectively, are both covered, divided to 10′ and read by opposing verniers and reading microscopes to 10″.

The telescope is mounted centrally on the horizontal axis, and can transit at either end. It has a fixed objective of aperture 3·5 cm. and focal length 25 cm., and a rack-focussing eyepiece tube, carrying a fixed cross-wire diaphragm and a screw-focussing inverting eyepiece. A sensitive spirit level is mounted in adjustable bearings longitudinally above the telescope, and another is fixed at right angles to this on the vernier plate, between the standards. The vertical circle is fixed to the telescope and transit axis, the vernier plate being fixed to one standard, and an axis clamp and tangent screw to the other. The trunnions on both standards are adjustable vertically. The instrument has a tribrach mounting, with three footscrews for levelling. These screws have flat ball and socket jointed footplates which rest on the tripod head. The attachment for fixing the theodolite to the tripod is the central screw and spring usual in German instruments, which permits a lateral adjustment of the theodolite over the station point without moving the tripod. Inv. 1876–1194.

198. TRANSIT THEODOLITE. Made by J. Wanschaff, Berlin.

This instrument, constructed about 1875, has the telescope and vertical circle fixed at opposite extremities of the horizontal axis, outside the bearings. This arrangement reduces the height of the instrument and permits the telescope to transit completely, but has the disadvantage that the telescope is not centred above the station point.

The horizontal circle has a diameter of 16 cm., is divided to 10′ and read by opposing verniers and reading microscopes to 10″. It is covered by a metal plate attached above the vernier plate, and fits fairly tightly on the vertical axis, but can be rotated independently for taking readings of an azimuth angle at various parts of the limb. The vernier plate has an axis clamp and tangent screw, and carries a central socket in which the vertical axis rotates. A horizontal bracket fixed across the top of this socket carries the bearings for the transit axis. Both bearings can be adjusted on the bracket, and tested for horizontality by a sensitive striding level. The transit axis has a clamp and slow-motion screw to fix it to the vertical socket. The vertical circle has a diameter of 10·5 cm., is divided to 20′ and reads by opposing verniers fixed to the axis bracket and magnifying lenses to 1′. The telescope has a fixed objective of 2·5-cm. aperture and 22-cm. focal length, and a rack-focussing eyepiece tube carrying a fixed cross-wire diaphragm and a slide-focussing inverting eyepiece. The instrument is mounted on a tribrach, with three footscrews.

Inv. 1876–1195.

199. TRANSIT THEODOLITE. Made by Elliott Bros. Presented by the Admiralty.

This instrument was made at the end of the 19th century and used in the British Antarctic Expedition, 1901. It has 7-in. vertical and horizontal circles, graduated every 10′ and reading by two opposing verniers and reading microscopes to 10″. All adjustable screws and parts are covered with wash leather to protect the operator's fingers from frost.

The horizontal and alidade circles are enclosed in a metal case, the verniers being covered by hinged plates. Clamps and tangent screws are fitted to both circles, and to the vertical circle, which is not covered, and is fixed to the transit axis. The vertical vernier bracket is clamped to a lug on one standard by opposing screws, and carries a sensitive spirit level perpendicular to the transit axis. The transit axis rests in Y-bearings on the standards, one trunnion being adjustable vertically, and is kept in position by metal retaining straps; it is hollow and has a lens at one end for illuminating the telescope axis. The telescope is rigidly fixed to this axis and transits at the eyepiece end only. It has an objective of 11-in. focal length and 1·5-in. aperture, focussed by a rack and pinion mechanism controlled from the eyepiece end. The diaphragm has one vertical and one horizontal thread, both adjustable laterally. Three slide-focussing eyepieces are provided, one inverting, one diagonal, and one erecting. There is a central reflector in the telescope for illuminating its axis by light coming through the transit axis from a lamp fixed to one standard. A striding level is provided for testing the transit axis. The vernier cover plate carries a spirit level, with its axis parallel to the transit axis, whilst a perpendicular level is fixed to one standard. A central compass with a 4-in. ring graduated in degrees is attached to the vernier plate.

The instrument has a tribrach mounting with three levelling footscrews, whose points rest in a trivet plate; this is provided with a locking plate of the Everest type attached to the tripod head. Inv. 1911–161.

200. TRAVELLER'S TRANSIT THEODOLITE. Made by L. Casella.

This is a compact theodolite specially designed for Alpine and military surveying. It has 3-in. vertical and horizontal circles, divided to half-degrees and read by verniers to single minutes. A diagonal eyepiece is provided for astronomical observations of stars near the zenith.

The construction of the instrument is similar to that of a modern vernier theodolite of twice the size. The transit axis rests on standards projecting from the vernier plate, and carries a central telescope and the vertical circle fixed to it. The vernier arm projects from one standard, and a tangent clamp and slow-motion screw is fitted to the other, which also carries a spirit level perpendicular to the transit axis. A similar level parallel to the transit axis is fixed on the vernier plate, which also carries a central compass box, having a 1½-in. ring divided in degrees. The compass needle is provided with a lifting lever for clamping it when desired. The vernier plate rotates independently about the vertical axis and has a clamp and tangent screw for connecting it to the horizontal circle, which has a similar clamp and tangent screw connecting it to the tribrach. This latter has three footscrews, with their feet clamped in a trivet plate by a locking plate of the Everest type. The trivet plate can be screwed to the tripod head. The telescope has a rack-focussing objective of

4·5-in. focal length and 0·65-in. aperture, a fixed cross-wire diaphragm and a set of slide-focussing eyepieces, one erecting, one inverting, and one diagonal. A reflector for illuminating the cross wires at night is fitted in front of the objective. Inv. 1893–147.

201. ENGINEER'S TRANSIT THEODOLITE. Made by W. & L. E. Gurley, Troy, New York.

This instrument illustrates many of the characteristics of modern American transit theodolites of the type used in reconnaissance and engineering surveying. The solar attachment to the telescope for determining meridians and latitudes by observations on the sun is a special feature, whilst the levelling base, with its "shifting centre" and four footscrews, is typical of American construction.

The horizontal circle has a diameter of 6·7 in., and is graduated on silver to 30′, reading by two opposite verniers to 1′. It is covered by a metal plate attached to the vernier plate and having windows above the verniers. The graduations on the limb are in two sets, one completely round the circle from 0° to 360°, the other in four quadrants from 0° to 90°. The figures are slightly inclined in the direction of increasing numbers. The vernier cover plate carries two spirit levels with their axes respectively parallel and at right angles to the transit axis. A large compass box, with a 5-in. ring graduated in half-degrees, is so mounted on the centre of the plate that its ring can be rotated in its own plane by a rack and pinion arrangement. The pivot of the needle is attached to a large plate, which can be lifted as a whole for clamping the needle. The standards for the transit axis terminate in Y-bearings, one of which is adjustable. The transit axis carries at one end a small spirit level, which can rotate about it, and be clamped in any position to rotate with the axis. At the opposite end is similarly mounted the vertical arc, its vernier being adjustably fixed to the corresponding standard. The arc is graduated every 20′ and reads by vernier to 30″; angles of elevation or depression up to 80° can be read. The telescope rigidly fixed to the axis, transits at either end. It has an 11 in. objective, of 13/16ths in. aperture, with a rack and pinion focussing movement, and an erecting eyepiece of magnification 26 diam., also rack focussing. Three parallel horizontal and one vertical platinum wires are mounted in the diaphragm, the two outer horizontal ones being for stadia work. A sensitive level, 7⅞-in. long, with a metal scale for reading the bubble is mounted beneath the telescope and can be adjusted by capstan screws at both ends.

The solar attachment is of the type invented by Burt, and is fixed to the top of the telescope, with its polar axis perpendicular to that of the telescope and the transit axis. This axis, and the hour circle attached to it, can be adjusted on the telescope to ensure perpendicularity. The hour circle is graduated every 5′, and has a diameter of 1·5 in. The declination arc, movable about the polar axis has a radius of 5 in., with a silver limb graduated every 15′ from 0° to 33°, and read by a vernier on the sighting arm to 30″. This sighting arm is mounted on the centre of the arc, and can be rotated with respect to it by a fine threaded screw. At each end of the arm is fixed a lens with a pin-hole stop and a silver reflecting plate on which are engraved parallel lines in two perpendicular directions, at a distance apart equal to the diameter of the sun's image. In using this attachment to find the true meridian, the co-latitude of the place is set off on the vertical arc, the declination of the sun corresponding to the date and time on the arc, and the hour on its circle, and the telescope is then rotated in azimuth until the sun's image, caused by refraction through the lens of the sighting arm, falls exactly between the lines on the mirror. The telescope and polar axis are then in the meridian. Inv. 1914–741.

202. TRANSIT THEODOLITE. Made and lent by C. F. Casella & Co., Ltd.

This is a 5-in. vernier theodolite of modern construction, the telescope having a fixed objective and internal focussing lens. A gradienter scale is fitted to the clamp of the vertical circle and is used for measuring distances.

The horizontal circle has a diameter of 5 in., and is divided to 20′ and read by two opposing verniers and reading microscopes to 20″. A metal cover plate is fixed to the vernier plate and protects the horizontal circle from dust. The standards and two mutually perpendicular spirit levels are mounted on this plate. Tangent clamps and slow-motion screws are fitted to both the vernier plate and the horizontal circle, so that azimuth angles can be repeated. A 4-in. trough compass can be attached beneath the horizontal circle, and rigidly connected to it, for orienting the instrument. The vertical circle has a diameter

of 4 in., is divided to 20′ and read by opposing verniers and microscopes to 30″. A sensitive spirit level is fixed to the vernier bracket, perpendicular to the transit axis. The telescope has a fixed objective of 1·25-in. aperture, and an internal lens, movable for focussing by means of a central screw operating the rack and pinion. This screw is conveniently placed at one end of the transit axis. The eyepiece is inverting, screw focussing and magnifies 20 diam. It can readily be removed to permit access to the diaphragm, which is fixed in the main telescope tube and is of the star pattern, with one horizontal and two equally inclined wires intersecting on the former. The gradienter scale is fixed to the clamping bracket of the vertical circle, the head of the tangent screw having a graduated drum reading hundredths of the scale divisions, each of which is one-hundredth of the distance between the transit axis and the axis of the tangent screw. In using the scale for measuring distances, the altitude angle of the telescope introduces a factor depending on the square of its cosine, the staff being vertical. The instrument has a tribrach mounting with three levelling screws, the feet of which rest in grooves in a trivet stage and are kept fixed by a locking plate. A knurled clamping screw serves to fix this stage to the tripod head, permitting a small centring movement without disturbing the tripod.

Inv. 1921–732.

203. VERNIER TRANSIT THEODOLITE. Made and lent by E. R. Watts & Son, Ltd.

The 4·6-in. horizontal and 4-in. vertical circles in this instrument are divided on silver to 20′ and read by two opposing verniers and reading microscopes to 20″. The telescope has an internal focussing lens and transits at both ends. The horizontal circle is enclosed in a dustproof and waterproof box, fixed to the vernier plate. The theodolite is clamped to the levelling tribrach by a centring device which permits the vertical axis to be set over the station point without moving the tribrach and tripod.

The telescope has a fixed objective of 1·7-in. aperture and a fixed glass diaphragm on which are engraved the usual cross lines and stadia lines. Owing to the anallatic properties of the internal focussing lens, no " constant " is necessary when using the theodolite as a tacheometer. The eyepiece is inverting and screw focussing.

The transit axis, on which are fixed the telescope and vertical circle, is permanently fixed on the standards, but the bearing at one end can be adjusted by means of a capstan screw. The horizontal circle is mounted on a repeating stage and has a separate axis clamp and tangent screw, carefully distinguished in shape from those operating the plate motion. The vertical vernier bracket is fixed adjustably to the standard in the ordinary manner, and carries the usual spirit level with its axis parallel to the vernier zeros. A similar bubble tube is mounted on the horizontal plate, parallel to the transit axis, and a very small bubble is fixed across one standard, perpendicular to the transit axis. A trough compass with the usual edge-bar needle and lifting arrangement is screwed across the other standard, and can be detached if required. The feet of the three levelling footscrews are tightly clamped in a trivet stage which screws on the tripod head, but has also pointed feet for setting it on a platform when the tripod is not necessary. The heads of the footscrews have dustproof caps, threaded in the tribrach ; these also serve to take up any wear on the footscrews. The graduation of the circles and the numbering of the divisions at every 5° are very distinct.

Inv. 1922–444.

204. MICROMETER MICROSCOPE TRANSIT THEODOLITE. Made by A. Lingke & Co., Freiberg. Lent by the Admiralty.

The precision of small theodolites has been greatly enhanced in recent years by the provision of micrometer microscopes for reading the circles to within a few seconds. The instrument exhibited, salved from a German warship sunk at Scapa, illustrates a type of theodolite of Continental design, with micrometer reading to both circles, the telescope and vertical circle being mounted eccentrically at one end of the transit axis. The horizontal and vertical circles, of diameters 14 cm. and 13 cm. respectively, are graduated on silver to 10′, and read by two opposing micrometer microscopes to 2″, the micrometer drums being graduated every 20″, and the tenths estimated.

The eccentric arrangement of the telescope has obvious disadvantages, but permits the telescope to transit independently of the height of the standards above the horizontal circle, and also enables longer microscopes to be employed with the vertical circle than is possible when the telescope is above the vertical axis.

These microscopes are mounted in a stage which is set on the transit axis and is permitted a slight rotation about this by means of a tangent screw attached to one standard. The stage carries a spirit level mounted in adjustable bearings, whereby the microscope can be set accurately horizontal. A second adjacent spirit level is mounted in a bracket on the transit axis, to which it can be clamped, and is prevented from fouling the microscope by stops, which abut against the vertical axial cone, but allow a small motion of the level. A separate axis clamp is connected with the tangent screw fitted to the second standard, and when tightened, permits a slow motion only of the transit axis. The telescope is screwed upon one end of this axis, the vertical circle being attached to it by a friction clutch permitting independent setting of the circle, but ensuring that the telescope and circle move together with the axis. An auxiliary vertical circle, 10-cm. diam., graduated in degrees and read by index, is mounted on the other end of the transit axis, and serves both to balance the instrument and to check the larger units of the vertical reading. The standards are fixed to a central hollow conical socket, and also carry the brackets supporting the two horizontal reading micrometer microscopes. This conical socket revolves about a central cone carried by the horizontal circle, which is fixed to the tribrach, and is provided with an axis clamp and tangent screw for slow motion.

The telescope has a sliding eyepiece, actuated by a rack and pinion arrangement and a fixed objective, of 22-cm. focal length and 2·5-cm. aperture. The eyepiece tube carries the diaphragm and a screw-focussing inverting eyepiece.

Inv. 1920–88.

205. MICROMETER TRANSIT THEODOLITE. Made and lent by T. Cooke & Sons, Ltd.

This design of a small transit theodolite exhibits many special features which render it capable of very accurate work. The horizontal circle, of 5-in. diam. and graduated directly to 10′, is completely enclosed in a metal sheath and is read by two micrometer microscopes to 10″, or even less by estimation. The vertical circle is likewise graduated and read, but is not enclosed. The telescope is focussed by means of an internal lens, the position of which can be varied by rotating a milled screw at one end of the transit axis.

In other respects the theodolite resembles an ordinary modern vernier reading type, with the usual tribrach mounting, the feet of the three levelling screws being clamped in a trivet plate which screws on to the tripod head. Tangent clamps and slow-motion screws are fitted to the independently rotating horizontal plate and limb, as also to the vertical circle, which is fixed to the transit axis. The microscopes for the horizontal circle are held rigidly by brackets projecting from the cover plate, and are " broken " near their eyepiece ends, so that they can be read more comfortably. At the other end their tubes are attached to the cover plate by translucent glass tubes which exclude dust but permit illumination of the limb. The microscopes for reading the vertical circle are rigidly fixed to a bracket to which is attached a long spirit level, perpendicular to the transit axis, and which is clamped to one standard by means of a projecting tongue. A perpendicular spirit level is also mounted on the cover plate. Both levels can be adjusted.

The telescope is mounted centrally on the transit axis and transits at either end. It has a 1·5-in. aperture objective lens, internal focussing lens and a screw-focussing inverting eyepiece of magnification 25 diam. The diaphragm is of glass, and has horizontal stadia lines of 1 : 100 ratio on each side of the main line, and is so fixed that, by a special key, it can be withdrawn and cleaned without upsetting the collimation setting.

A special type of trough compass, with a flat-nosed needle, read from one end, can be screwed to one of the standards. The needle is clamped or released by turning the milled screw at the non-reading end. Inv. 1922–205.

206. MICROMETER TRANSIT THEODOLITE. Made and lent by E. R. Watts and Son, Ltd.

In this example of a modern theodolite of small size, both the vertical and horizontal circles are read by two opposing micrometer microscopes, rigidly fixed to the standards ; the objective tubes of these microscopes are vertical, but prismatic reflectors are fitted to deflect the light into the horizontal eyepieces and also, in the case of the vertical circle microscopes, into the objectives.

Both circles have a diameter of 5 in. and are divided on silver to 10′, every degree being numbered. The micrometer drums are graduated into sixty parts, each division thus corresponding to 10″ on the circle ; it is, however, quite easy to

set the micrometer wire to within a single second of arc, and to read the drum to this amount. The circles are both enclosed completely in dustproof metal boxes, fixed to the standards.

The telescope is centrally mounted on the transit axis, and has a fixed objective of 1·5-in. aperture and 8-in. focal length ; its tube is dustproof, being terminated at the other end by a fixed glass diaphragm upon which the image is focussed by means of a movable internal concave lens, operated by a milled screw outside the tube. Slide-focussing eyepieces of different powers are provided. The vertical circle is fixed to one side of the telescope and revolves with it on the transit axis.

The horizontal circle can revolve independently of the upper plate for repeating azimuth angles, and has a separate axis clamp and tangent screw for slow motion. The instrument has a tribrach mounting, with three levelling footscrews. A self-centring arrangement is fitted whereby the vertical axis can be displaced laterally through a range of $\frac{3}{4}$ in. in any direction without disturbing the tribrach or the tripod to which it is screwed.

Two small bubble tubes are fixed to the horizontal cover plate with their axes respectively perpendicular and parallel to the transit axis ; a more sensitive level is mounted on the vertical microscope brackets, and a specially sensitive striding level is provided for testing the horizontality of the transit axis. Inv. 1922–445.

MISCELLANEOUS INSTRUMENTS AND ACCESSORIES.

207. SMALL UNIVERSAL INSTRUMENT.

This is a 17th-century instrument for measuring angles in either a vertical or a horizontal plane.

It consists of a wooden rectangular frame to which can be screwed a brass socket in either of two positions for setting the plane of the rectangle horizontal or vertical. Two adjacent sides of the rectangle have folding brass sights at their corners for setting off right angles. A movable brass index arm, provided with folding sights, is centred on one of the sighted sides of the rectangle and rotates over a brass scale mounted on the other side. This scale is graduated to read tangents, to the nearest tenth. A clamp and screw fixed to the index arm serve to clamp it in any desired position to a brass arc fixed to the rectangle. The outer sight on the arm carries a plumb-line when the rectangle is horizontal. When vertical angles are being measured, the plumb-line is detached and fixed to a screw so that it hangs parallel to the brass scale in the plane of the rectangle.

Inv. 1917–77.

208. TROUGHTON DIP SECTOR. Made by Thos. Jones. Presented by the Admiralty.

The Dip-Sector was first designed and made by Troughton for measuring the " dip of the horizon " from an elevated observing point. The example shown was made in the early part of the 19th century.

The graduated sector, index arm, index mirror and horizon mirror are the same as in the sextant, but the telescope has its eyepiece at right angles to its objective, a reflecting mirror being interposed between the two. This enables the observer to measure the zenith angle between the apparent horizon lines to his left and right. By rotating the handle through a half turn, he can measure the corresponding nadir angle. The quarter of the difference between these two readings is the required dip angle between his apparent and true horizons. The index error is eliminated in this method. The sector has a radius of 7 in. and is divided on silver from 5° to 40° every 10′ and read by vernier to 10″. The actual angles are only half the graduation angle, as in the sextant, but the angle read is the correct one between the two sight lines. The horizon mirror, fixed to the sector, is partly silvered and parly unsilvered. The index glass, which rotates with the index arm, is wholly silvered, and has a central index. The arm carries the vernier, and can be clamped to the sector at any point, further rotation being effected by a tangent screw. The telescope can be adjusted to vary its lateral distance from the sector by a screw, and the handle can be rotated and clamped in any position parallel to the face of the sector. Inv. 1876–1207.

209. BOX SEXTANT. Made and lent by Newton & Co.

This example is typical of the box sextant invented by William Jones at the beginning of the 19th century. In principle, it measures angles like the sextant, but its fixed and movable mirrors are enclosed in a circular brass box, which has

an aperture sighting hole and opposing window cut in its circular side. The index mirror is rotated from without the box by means of a milled head and pinion gears, and the external vernier arm is fixed on the same pivot axis as this mirror and measures its rotation on a graduated arc engraved on a silver strip embedded in the upper external surface of the box.

The arc is divided to quarter-degrees, numbered as if they were half-degrees, since the angle sighted is double the angle through which the index mirror and arm rotate, and is read by vernier on the index arm to single minutes ; a pivoted magnifying lens is fitted for assisting the reading of the vernier. The brass cover which protects the external parts when the instrument is not in use, can be screwed to the under part of the box when sights are taken, and serves as a hand grip. The radius of the divided arc is only 2 in., so that the instrument is less accurate than an ordinary sextant, but it is preferred for rough reconnaissance surveying on account of its portability and the protection of its parts afforded by the box.

The horizon mirror can be adjusted from outside the box by means of a key, and coloured glasses are provided for taking sights on the sun.

Inv. 1865–5.

210. PAGET ANGLE SEXTANT. Made by Hughes & Son. Presented by the Admiralty.

This instrument is very similar to the ordinary box sextant with open sides and is used for measuring angles in any plane. One object is viewed directly through a lateral aperture and the unsilvered half of a fixed mirror, whilst the other is viewed after double reflection at the surface of a rotating mirror and the silvered half of the fixed one.

An index geared to the rotating mirror measures the angle between the two objects on the graduated limb of the top surface of the instrument. A hand grip is screwed to the bottom surface. The index arm is so geared to the revolving mirror that it rotates through four times the angle through which this mirror turns ; this is twice the angle through which the doubly reflected ray rotates. Hence the limb is graduated in degrees, numbered as if they were half-degrees. Both mirrors have their faces perpendicular to the plane of the angle measured. A metal index in front of the axis of the rotating mirror marks the central line of sight.

Inv. 1911–220.

211. AERIAL POSITION FINDER. Presented by the Admiralty.

This instrument is a crude form of altazimuth theodolite, designed for approximately locating the position of aerial objects. The altitude and azimuth angles of such an object can be measured at any moment to the nearest tenth of a degree.

It consists of a massive, horizontal, graduated circle of 16 in. diam., divided in degrees and read by estimation to the nearest tenth-degree by means of the pointed end of a rotating alidade, pivoted at the centre of the circle. Three footscrews and a pair of perpendicular spirit levels are fixed to the circle for levelling it. The feet of the footscrews rest on three footplates, of which the upper surfaces have a plane, a straight groove and a conical hole respectively. The footplates are fixed to a stand and serve to keep the circle fixed without straining it. The alidade has a vertical bracket fixed at the end opposite to its pointer for supporting the vertical arc and sighting tube, which are pivoted about a horizontal axis at its upper extremity. The vertical arc is a quadrant of 8 in. radius, graduated in degrees and read by an index fixed to the bracket. The sighting tube is fixed parallel to one radius of the quadrant and moves with it. The tube is 30 in. long and carries a blade foresight and aperture backsight, the latter having a rubber protecting eyepiece. There are no clamps to the motions, the friction at the pivots being great enough to prevent the instrument moving after it has been set. Two small electric bulbs set in conical reflectors on the alidade can illuminate the circles for night reading, a battery and operating switch for this purpose being provided and exhibited with the instrument.

Inv. 1920–583.

212. COMBINED THEODOLITE AND CROSS HEAD.

This instrument, probably of fairly modern French construction, has a hollow brass cylinder of 13 cm. diam., divided into two parts independently movable about the common vertical axis, instead of the horizontal and vernier plates of an ordinary theodolite.

The upper half of the cylinder carries the standards for supporting the horizontal axis of rotation of the telescope. A spirit level is mounted in adjustable

bearings between these standards and is used for setting the axis of the cylinder vertical. The curved face of this half is pierced by two pairs of vertical sighting slits at opposite ends of perpendicular diameters, and the lower circular edge, which is in contact with the lower half cylinder, has two opposing vernier scales engraved on it. The corresponding edge of the lower half is graduated in degrees, and read by the verniers to 2′. This half, which has a single pair of vertical sighting slits pierced in its surfaces, is mounted upon a tribrach provided with the usual three footscrews, and is fitted with a clamp and tangent screw for slow motion. The upper half cylinder can be rotated with respect to the lower half by a toothed wheel and pinion mechanism, actuated by a milled screw beneath the cylinder.

The telescope is mounted so as to be always in the same vertical plane as the vernier zeros of the upper half cylinder. It has a fixed objective of 1-in. aperture and 7-in. focal length, and a rack-focussing eyepiece tube with a slide-focussing inverting eyepiece.

The head of the tripod used with this instrument is also exhibited and illustrates the type usual in French construction. It is of wood, with brass slots for the feet of the tribrach, and is connected to the theodolite by a central plunger screw with opposing spring, which permits the small displacement of the instrument necessary for setting it horizontal. Inv. 1919–415.

213. PERISCOPE THEODOLITE. Made by Troughton & Simms. Lent by the War Office.

This instrument was designed during the war, 1914–18, for surveying from the front line trenches. The periscope attachment to the objective end of the telescope enables the observer to take azimuth angles without exposing himself or the theodolite. The latter is similar to an ordinary 3-in. vernier theodolite, except that the telescope is " broken " by a diagonal mirror in the transit axis, one half of which is hollow and forms the eyepiece tube, perpendicular to the objective tube. When in use the objective tube is vertical, pointing to the zenith, and a counterpoise fixed to its lower end below the transit axis balances the weight of the periscope. The axis of rotation of the periscope mirror is perpendicular to the transit axis, and the mirror is adjusted about this axis by means of a long brass chain. This adjustment varies the vertical angle of the line of sight, but does not change its azimuth.

The 3-in. horizontal circle is graduated in half-degrees and read by opposing verniers and readers to 1′. A similar vertical circle is attached to the transit axis and read by opposing verniers fixed to the standards, but is not used with the periscope attachment. The horizontal vernier plate covers the divided circle except at the verniers and carries a spirit-level parallel to the transit axis. A perpendicular spirit-level is attached to the vertical vernier bracket. A trough compass is fitted beneath the horizontal circle and rotates with it about the vertical axis. Clamps and tangent screws are fitted to the vertical and horizontal circles, and the horizontal vernier plate. The theodolite has a tribrach mounting, with three levelling screws, which rest in a trivet stage and are locked in position by a locking plate of the Everest type. A shifting centre arrangement serves to attach the trivet stage to the tripod head, but permits a relative horizontal displacement of the two when the clamping screw is loosened.

Inv. 1919–495.

214. THREE READING MICROSCOPES. Made by O. Fennel Söhne, Cassel.

These represent three types of microscope for reading the circles of small theodolites. In each case, the circles are completely enclosed in metal, dust-proof cases, and the microscopes are consequently provided with mirror reflecting tubes for illuminating the graduations.

The first microscope is a " Schätz " or " Estimation " Microscope, and has a single fixed line marked in its focal plane, parallel to the graduations of the circle. It is used in theodolites having 10-cm. circles, graduated every 10′. The position of the fixed microscope line between these graduations is estimated to a single minute.

(*See* " Zeitschrift für Vermessungswesen," 1902, p. 214–216.)

The second microscope, known as a " Nonien-Mikroskop," has a fixed vernier scale marked in its focal plane, and is used for theodolites having 13-cm. circles graduated to 5′. Ten divisions of the vernier scale correspond to nine of the circle, whence the position of the zero vernier line can be read to 30″, or even to 15″ by estimation. Alternate graduations of the vernier scale are numbered consecutively from 0 to 5, and represent minutes.

(*See* " Zeitschrift für Instrumentenkunde," 1912, Part V.)

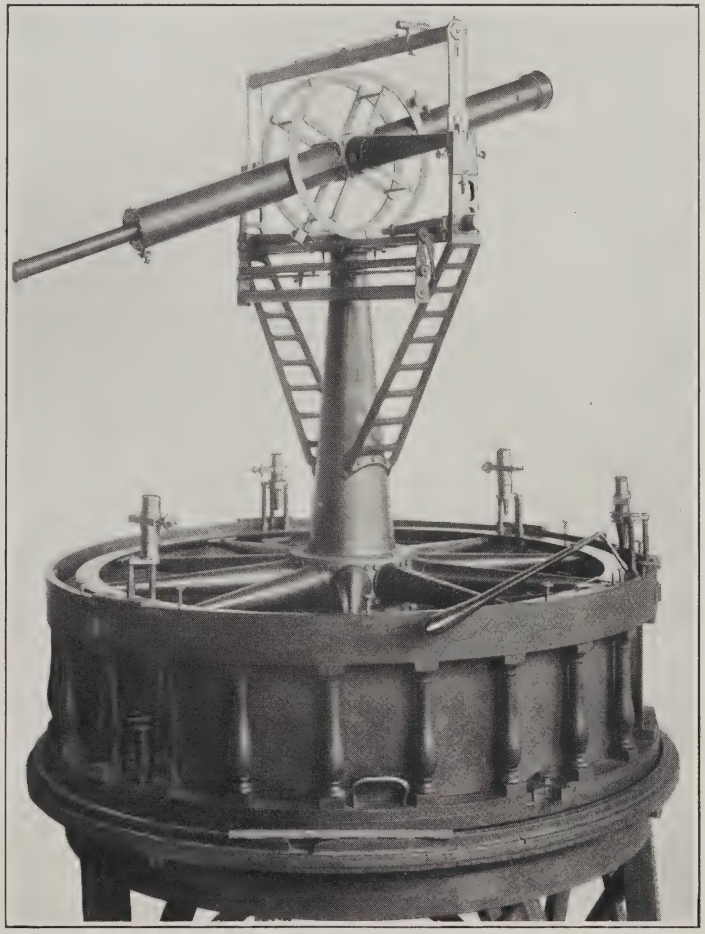

Fig. 1. 3-ft. Theodolite, by Ramsden, p. 83.

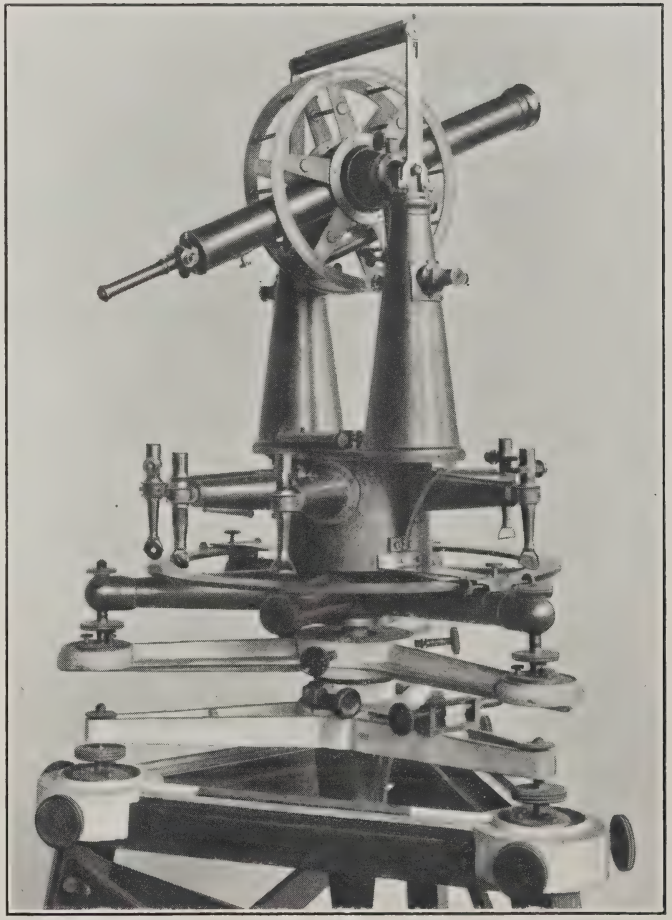

Fig. 2. 2-ft. Theodolite, by Troughton & Simms, p. 84.

PLATE V.

The third microscope, designated a "Skalen-Mikroskop," is of the type devised by Hensoldt in 1879, and is used on theodolites having 13·5-cm. circles, graduated in 20′. A fixed scale in the focal plane of the microscope has ten divisions, numbered right to left, exactly covering the interval between consecutive graduations of the circle. The position of one circle graduation on this scale can be read to one-tenth of a scale division, *i.e.*, to 12″. In this and the second microscope, the reading edges of the two scales slightly overlap each other, which ensures a sharper reading.

(*See* "Zeitschrift für Vermessungswesen," 1879, pp. 497–507.)

Inv. 1914–553, 554, 555.

215. QUICK-LEVELLING TRIPOD HEAD. Made and lent by T. Cooke & Sons, Ltd., York.

For setting up a surveying instrument on uneven ground, the tripod head is often provided with an arrangement permitting the instrument to be quickly levelled, without moving the legs of the tripod or the foot-screws, which last are only used in the final accurate levelling.

Such a device is here exhibited. The trivet stage of the instrument is screwed to a central spherical section of a hollow ball, which fits sufficiently closely into a spherical socket fixed to the tripod legs to prevent any motion other than a rotation of the ball in the socket, permitting the top of the ball to be levelled irrespective of the top of the tripod socket. A circumferential clamp, provided with three thumb pieces, is threaded upon the outside of the socket, and serves to clamp the ball tightly within this when the instrument is approximately level, as shown by a small circular spirit level fixed in the top of the ball. A shank attached beneath the top plate of the ball marks its centre, and has a loop of cord attached for centring the instrument over the station point.

Inv. 1921–561.

216. SHIFTING CENTRE TRIPOD HEAD. Made and lent by T. Cooke & Sons, Ltd., York.

This tripod head is fitted with a "shifting centre" arrangement, permitting the centre of the attached theodolite to be displaced any distance up to about 1 in. in any direction without removing the theodolite from the tripod or altering the position of this latter. This property is very useful in setting the theodolite accurately over the station point.

The tripod head consists of five metal parts, namely a threaded plate to which the theodolite is screwed, a shoulder plate to which the tripod legs are attached, and three other parts which together form a collar, between the flanges of which the other two plates can be clamped. The outer diameter of the collar is 1¼ in., whilst the theodolite base plate and tripod shoulder plate have central apertures 2 in. and 2½ in. diam. respectively, so that either of them can be moved between the flanges independently, and clamped in the required relative position.

A small circular spirit level is embedded in the top of the tripod plate and is used to set this approximately level. Inv. 1921–559.

GEODETIC THEODOLITES.

217. RAMSDEN'S 3-ft. THEODOLITE. Presented by the Ordnance Survey. Plate V, Fig. 1, p. 83.

The main angles of the Principal Triangulation of Great Britain and Ireland were mostly measured with this altazimuth theodolite, or with a very similar one now in the possession of the Royal Society. The latter was made by Ramsden in 1787 and the one here exhibited about 1790; both were in constant use between 1792 and 1862, and several sights were taken with them during the Principal Triangulation at distances exceeding 100 miles.

The theodolite here exhibited has a 3-ft. horizontal circle, divided to 10′ and read to 1″ by three micrometer microscopes. The circle is mounted upon ten conical radii, which project from the outer conical vertical axis; this revolves upon an inner fixed axis to which the reading microscopes and levelling foot screws are fixed. A flat horizontal bar rigidly mounted across the top of the outer axis supports the telescope axis. Two 10·5-in. vertical circles, divided to 30′, are fixed to the telescope and read to 3″ by single microscopes mounted on the supporting bar. The telescope axis and supporting bar are made accurately horizontal by means of two spirit levels, one 24 in. and the other 21 in. long.

The telescope objective has a clear aperture of 2·5 in. and a focal length of 36 in. The erecting eyepiece generally employed magnifies 54 diam., but other eyepieces were used in special cases. The telescope diaphragm has fixed cross wires and a horizontal travelling wire controlled by a micrometer screw, and could be illuminated through the horizontal axis of rotation for night readings. Clamps and tangent screws for fine adjustment are fitted to the horizontal and vertical circles.

The probable error of a single observation with this instrument was about 2″ for distances up to 70 miles.

The mechanism of the microscope is illustrated in the accompanying diagram. (*See* No. 218.)

(*See* "Phil. Trans. Roy. Soc.," Vol. LXXX, 1790, p. 111. "Account of the Principal Triangulation," "Ordnance Survey, 1858.")

Inv. 1876–1203, S.M. 259.

218. DIAGRAM OF MICROMETER MICROSCOPE. (Ramsden's 3-ft. Theodolite.) Constructed in the Museum.

The method of reading a graduated scale by means of a micrometer microscope having at its focal plane a movable cross wire, was first applied to theodolites by Ramsden in the construction of his 3-ft. instruments. The diagram shows the details of his later microscopes, which were added to the original two of his theodolites, and which differ very slightly from those.

The microscope has a single objective lens fixed in a tube, which is mounted in the supporting bracket and can be slightly adjusted towards or from the graduated circle of the theodolite. The base of the micrometer box is screwed to the top of this tube and has a smaller one screwed into its top; the latter carries a slide-focussing eyepiece of the usual Ramsden type.

The micrometer box contains two adjustable stages having their inner surfaces contiguous and their outer surfaces touching the walls of the box. The lower edge of the aperture of the upper stage has divisions notched in it at intervals of a hundredth of an inch, every fifth notch larger than the rest. The interval between the larger scale divisions is the same as that between adjacent divisions of the graduated circle when the latter interval is magnified by the microscope objective. Thus the interval between consecutive notches is 1′ of arc on the circle. The lower stage has a cross hair attached to its inner face, and can be moved as a whole across the notched scale by rotating the micrometer head; this head is threaded on to a screwed pin fixed to one end of the stage, and is pressed against the micrometer box by a counter helical spring inside the box. The pin has 100 threads per inch, so that the cross hair moves over one division of the notched scale at each revolution of the micrometer head. The periphery of the drum on this head is divided into 60 parts, and its rotation read by the position of a knife edge fixed to the box. Thus a rotation of the drum through one division of its periphery causes the cross hair to travel through 1″ of arc on the circle.

The stage carrying the notched scale can be adjusted in the box by means of a screw and counter V-spring acting on its ends until the cross hair lies over a notch when the micrometer drum reads zero. Inv. 1921–556.

219. 2-ft. TRANSIT THEODOLITE. Made by Troughton and Simms. Presented by the Ordnance Survey. Plate V, Fig. 2, p. 83.

This instrument was made at the commencement of the Irish survey and was first used in 1828 for checking the measurement of the Lough Foyle base by triangulation. It was further employed between 1829 and 1862 in measuring the main angles of the Principal Triangulation of Great Britain and Ireland.

This theodolite differs from the adjacent 3-ft. one made by Ramsden in that its telescope can transit completely between the supporting pillars, and the horizontal circle is mounted upon a repeating stage so that both circle and microscopes can be independently rotated. The horizontal circle is 2 ft. in diam., and is divided on silver to 5′ and read by five microscopes to 1″. Two vertical circles of 12-in. diam. are fixed to the telescope; they are divided to 5′ and read by single microscopes to 2″. The telescope has a fixed objective of 27-in. focal length and 2·1-in. aperture, and a rack-focussing eyepiece tube carrying the diaphragm and erecting eyepiece. The diaphragm has one fixed horizontal and two fixed diagonal wires, with five equidistant vertical wires moved laterally by a micrometer screw.

The repeating stage rests by means of three footscrews upon an iron triangle fixed upon the head of the wooden tripod stand. It has an upper rotating tribrach supporting the horizontal circle and vertical axis of the theodolite. The five microscopes reading this circle rotate with the telescope and upper part about this axis. Clamps and tangent screws are fitted to both circles and the repeating stage, and four spirit levels are provided for adjusting the telescope and horizontal axis of rotation.

(*See* "Account of the Measurement of the Lough Foyle Base," Ordnance Survey, 1847, p. 108.) Inv. 1876–1204, S.M. 260.

220. 40-cm. TRANSIT THEODOLITE. Made by Brunner Frères, Paris. Lent by the Physical Department, Ministry of Public Works, Egypt.

This instrument was ordered in 1858 for use in a projected general survey of Egypt. It has horizontal and vertical circles, each 40-cm. diam., graduated direct on silver to 5′, and each read by four micrometer microscopes direct to 2″, by estimation to 0·2″.

The vertical circle, together with a circle of equal dimensions as a counterpoise, is fixed directly to the horizontal axis of rotation of the telescope. This axis rests in bearings upon two standards which carry, opposite the two ends of the axis, fixed brackets for supporting the circle carrying the microscopes at one end and a counterpoise at the other. The axis of the telescope is pierced by a cylindrical hole for illuminating the interior, and a lamp can be attached to one of the brackets for this purpose. The standards project from a horizontal stage fixed to the alidade platform by adjustable screws, operated by a worm-wheel and pinion mechanism. These serve to level the stage more precisely after the alidade has been approximately levelled by the three footscrews attached to the horizontal circle. A striding level fitted parallel to the axis of rotation of the telescope, together with a perpendicular level fixed to the microscope circle, is used for levelling. The alidade platform carries the four microscopes for reading the graduated horizontal scale, and can be rotated in azimuth, carrying the whole upper portion with it. The horizontal circle itself is fixed to the three footscrews, but its graduated circle can be independently rotated for "repeating" angles. In addition to the microscopes, there is an index arm with a reading lens for checking the major readings of each circle. Tangent clamps and slow-motion screws are fitted to both the vertical circle and the alidade.

The telescope has an objective of 2·2-in. aperture and 30-in. focal length and an inverting draw-focussing Ramsden eyepiece, to which is fitted a micrometer stage having one horizontal and five vertical fixed threads, and one vertical thread movable by means of the micrometer screw.

The reading microscopes are fitted with metallic mirrors, and the vertical circle ones have prism reflectors in addition, for illuminating the field.

Inv. 1921–479.

221. 12-in. EVEREST THEODOLITE. Made by T. Cooke & Sons, Ltd. Lent by the Ordnance Survey.

Theodolites of this type were used by the Ordnance Survey in the Secondary Triangulation of the United Kingdom during the latter half of the 19th century. The example shown was made in 1884, and the probable error of a single observation made with it was about one second of arc.

The telescope is mounted on very low standards, so that it cannot be transited, whilst the vertical arcs only extend for some 40° on each side of the horizontal. The horizontal circle is mounted on a separate vertical axis for repeating azimuth angles. When this axis is clamped the verniers revolve with the standards; when unclamped, the circle, verniers and standards rotate together. The circle is of 12-in. diam., divided on silver to 5′ and read by four symmetrical verniers to 5″; four small microscopes are mounted on a separate rotating bracket for reading these verniers. The circle is mounted in a tribrach stiffened by a circular ring, used for lifting the theodolite. The three levelling screws threaded in the tribrach arms rest in radial V-shaped grooves in a base plate. The latter rests in turn on a trivet stage having a massive curb and three footscrews; three horizontal radial screws threaded in this curb press on the central boss of the base plate and serve to adjust the theodolite axis over the station point.

The four horizontal verniers are rigidly fixed to the standards which are about 6 in. high and support the central telescope, vertical arcs, vertical verniers and counterpoise. The two vertical arcs are portions of a circle of 12-in. diam.,

divided on silver to 10′ and read by opposing verniers and reading microscopes to 10″. The arcs are fixed to the axis of rotation carrying the telescope and counterpoise, whilst the verniers are clamped to one standard. The telescope has a rack-focussing objective of 2·5-in. aperture and 20-in. focal length, a fixed star diaphragm, and a slide-focussing Ramsden eyepiece.

The usual clamping and tangent screws are provided for all motions in azimuth and altitude, and two sensitive levels are supplied, one on the vertical vernier bracket, the other at right angles on the base of the standards. Inv. 1895–48.

222. 12-in. TRANSIT THEODOLITE. Made by E. R. Watts & Son. Lent by the Ordnance Survey. Plate VI, Fig. 1, p. 86.

This theodolite was constructed in 1910 for use on the Primary (First Order) Triangulation of the United Kingdom and has already been used to observe the angles of a piece of test triangulation in North-East Scotland in 1911–12, when 29 angles were observed with a mean error of 0·517″ per angle.

It is a transit theodolite with a repeating horizontal circle of 12-in. diam., read by three micrometer microscopes to 1″ and by estimation to 0·1″. A separate pointer microscope serves to check the integral degrees of the reading. The circle is protected from dust by a cover plate provided with apertures for the tubular microscope reflectors which form dustproof connections to the microscopes. The outer vertical axis is rigidly connected to a strong tribrach fitted at the ends of its arms with levelling footscrews and strengthened by a strong metal ring, covered with leather, which serves to lift the instrument. The footscrews rest in radial V-shaped notches on a lower tribrach plate which rests upon a strong circular baseplate having a massive curb. The lower tribrach has a central boss projecting through an aperture in the base plate; three radial screws threaded in the curb impinge on this boss and serve to move the whole instrument accurately over the station point. The vertical axis has a central socket in which can be inserted a nadir telescope for this centring operation.

The massive U-shaped standards for supporting the telescope axis of rotation are cast in one piece and attached to the cover plate of the horizontal circle, which also carries two mutually perpendicular spirit levels for setting the plate horizontal. The telescope axis is hollow and thus permits the diaphragm to be illuminated by an electric lamp supported on one standard, the light being reflected down the axis of sight by a central diagonal reflector inside the telescope. The latter has a fixed objective of 3-in. aperture and 24-in. focal length and a rack-focussing micrometer eyepiece tube in which various inverting eyepieces of powers 72, 50 and 30 diam. can be fitted. A 6-in. vertical circle, reading by two fixed verniers to 1′ is attached to the telescope and rotates with it; the vernier bracket, which carries a sensitive spirit level parallel to the telescope axis, is clamped to one standard. A very sensitive striding level is mounted on the telescope axis pivots; its bubble moves about 0·1 in. per 1″ difference of elevation.

For testing the cylindricity of the telescope axis, an arrangement designed on the principle advocated by Sir David Gill is provided (*see* "Report of Geodetic Survey of South Africa," 1896, p. 123). Its micrometer drum reads to 0·00001 in.

All the circles are fitted with clamps and tangent screws for slow motion.

Inv. 1914–103, S.M. 1366, 1367 and 1368.

FIELD ASTRONOMY.

Survey stations have to be referred to the standard system of lines of latitude and longitude by means of occasional astronomical observations. These observations also serve as checks upon the ordinary survey measurements, and can even replace such measurements in special cases. The determination of the latitudes of important towns and the directions of the meridians through them was an important task of ancient astronomy, and the Alexandrian geographer Ptolemy showed his appreciation of the necessary astronomical basis of map-making by giving the latitude and longitude of every important place

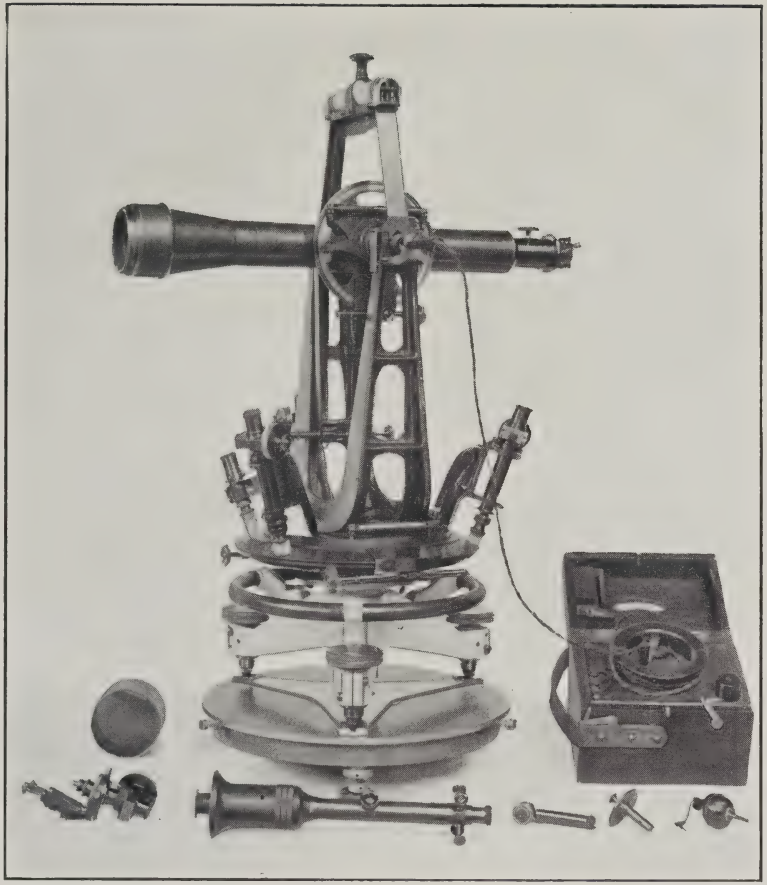

Fig. 1. 12-in. Theodolite, by Watts, p. 86.

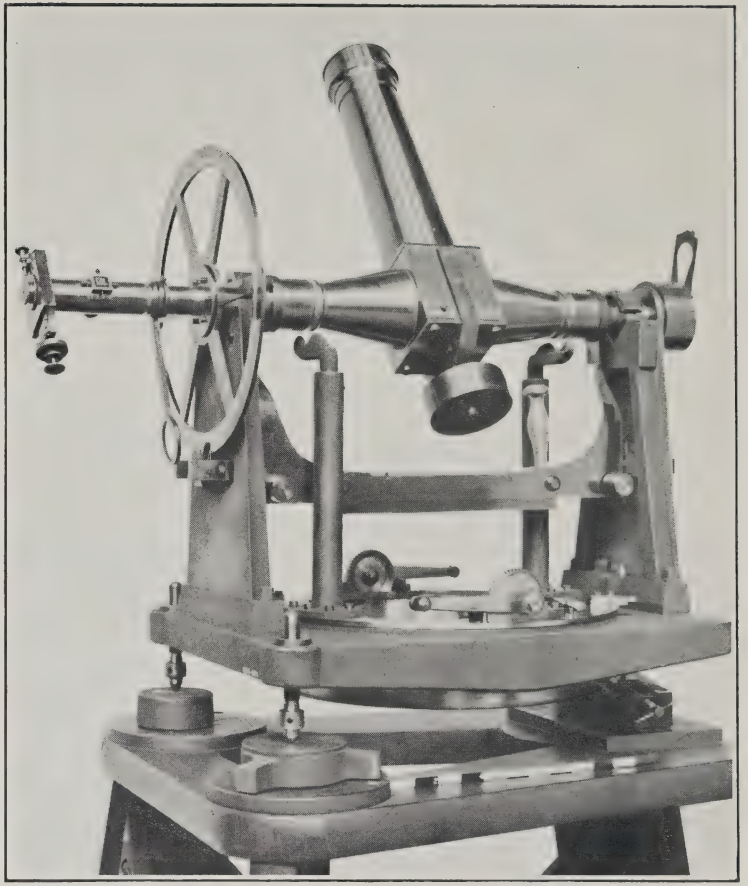

Fig. 2. Transit, by Brauer, p. 89.

known in his day. Unfortunately, Ptolemy's figures are mostly illusory, since the actual astronomical measurements made up to his time were too crude and scanty to provide an accurate basis for his maps. In a few cases, latitudes had been observed by means of stationary gnomons; in many cases, however, he relied upon the observations of travellers who professed to have reckoned the lengths of the longest days at the various places visited by them; whilst for longitudes few data besides the crude dead reckoning of sailors and travellers were available. The Arabs developed both stationary and portable astronomical instruments for determining latitudes and meridians, and did much to equip the early European navigators with the astrolabes, quadrants, compasses, dials and hour-glasses, which enabled them to determine their positions and construct the celebrated sea-charts of the Middle Ages. During the great arc measurements of the 17th and 18th centuries, the determination of latitudes and meridians was of fundamental importance, and instruments of large proportions were devised to obtain the necessary precision in these measurements, particularly in the latitude ones. For the latter purpose, sectors of circles of several feet radius were constructed to measure the altitudes or zenith distances of stars. The sectors made by Graham for the Lapland Arc Measurement in 1736, by Ramsden about 1800 for the Trigonometrical Survey of Great Britain, and by Troughton about the same date for use in America (*see* No. 224), illustrate the type of instrument used at that period. Airy's Zenith Sector (*see* No. 223), which replaced Ramsden's on the Trigonometrical Survey of Britain, shows the tendency to replace the plummet of the earlier sectors by the spirit level now generally employed. During the 19th century the increasing accuracy of graduation induced geodetic surveyors to use transits or altazimuths provided with small but complete divided circles instead of the earlier sectors, and Struve, in his arc measurements in Northern Europe, relied upon instruments of the type exhibited (No. 227). An important feature of such instruments is the micrometer eyepiece, with which in many cases the actual observations were made, the circles only being employed for approximately setting the telescope. In the zenith telescope, now mostly used in Europe and America for latitude determinations by Talcott's method of measuring the small difference in the zenith distances of two stars, this reliance upon micrometer measurement with the telescope immovable is also illustrated. The prismatic astrolabe (*see* No. 229), devised about 1900 by Claude and Driencourt for determining latitudes by the method of equal altitudes, represents another method of avoiding measurements upon vertical arcs and has found increasing favour where the highest degree of precision is not required.

The determination of longitude was for long a matter of extreme difficulty. Lunar observations were troublesome and required elaborate calculations, whilst chronometers were disturbed during long voyages and journeys. With the rapid development of electrical signalling during the 19th and 20th centuries, however, the difficulties of comparing the local time found by celestial observations with the standard time have been largely overcome, and longitudes can now be obtained with a high degree of accuracy. In determining local time by means of timing the transits of stars in the meridian, the electric chronograph, especially when controlled by a transit micrometer fitted to the transit telescope, has much reduced the personal errors of observation.

223. AIRY'S ZENITH SECTOR. Presented by the Ordnance Survey.

On the destruction by fire at the Tower of London of Ramsden's zenith. sector, which had previously been used to determine latitudes in the Principal Triangulation of Great Britain and Ireland, this sector was designed by Sir George Airy and constructed under his direction. It was used between 1842 and 1850 for determining the latitudes of twenty-seven stations of the Principal Triangulation.

The telescope is pivoted horizontally to a revolving gunmetal frame which is itself pivoted vertically in a fixed cast-iron framework. The latter is supported by three levelling screws upon a rectangular plate which in turn rests upon a cast-iron trough; this trough was usually screwed upon heavy wooden pickets driven into the ground.

Four micrometer microscopes attached to the telescope serve to read its inclination to the zenith upon two graduated arcs, mounted upon the revolving frame. Each arc extends over 45° of a circle of radius 20·5 in., and is divided to 5′ and read by the microscopes to one-quarter of a second.

The telescope has an objective of aperture 3·7 in. and 46 in. focal length, a micrometer diaphragm with five fixed and one movable wires, and an inverting eyepiece of magnification 70.

Three sensitive spirit levels are fixed in adjustable bearings across the back of the revolving frame.

In taking observations of a star's transit, the frame is quickly rotated to permit face east and face west readings of the telescope.

The probable error of a single observation of latitude with this instrument was about 1″.

(*See* " Astronomical Observations made with Airy's Zenith Sector," Ordnance Survey, 1852.) Inv. 1876–1202.

224. ZENITH SECTOR. Made by Troughton.

This portable sector was made at the beginning of the 19th century for use in America and was afterwards transferred to Copenhagen.

The main telescope for observing stars near the zenith is pivoted horizontally near its objective end to the top of a vertical hollow brass cylinder, which carries at its lower end the fixed graduated sector over which the eyepiece of the telescope rotates. Two micrometer microscopes fixed to the telescope serve to read its inclination to the vertical upon separate scales engraved on the sector. The scales, each of which covers about 15° and is divided to 3′, start at opposite ends of the sector and overlap about 5° in the centre. A third scale, continuous across the whole sector, is read by an index and serves as a check.

The telescope has an objective of 2·5-in. aperture and 45-in. focal length, and a diagonal eyepiece. Its motion over the sector is controlled by a clamp and tangent screw.

The base of the vertical cylinder is connected to a horizontal circle by six vertical pillars and can rotate with this circle about a vertical axis coincident with the cylinder axis. A long plummet suspended within the cylinder along its axis rests in a water vessel, inside the pillars, and serves to set the axis vertical. Its position is observed by two perpendicular microscopes fixed in the cylinder below the graduated sector.

A small telescope pivoted to the cylinder is used to observe circumpolar stars for setting the sector in the meridian.

The horizontal circle has a diameter of 9 in. and is divided to 10′. The vertical axis revolves inside a conical socket fixed to the tribrach, which carries three verniers for reading the circle to 10″. The three levelling foot screws of the tribrach rest on the top plate of a strong mahogany tripod. A small spirit level is mounted on the cylinder for rough levelling, and an adjustable counterpoise balances the telescope.

(*See* Pearson's Astronomy, 1829, Vol. II, p. 546.) Inv. 1891–24, S.M. 1943.

225. PHOTOGRAPHS OF ZENITH SECTOR. Lent by Prof. J. Norman Lockyer, C.B., F.R.S.

The zenith sector represented in these two photographs was designed by Lt.-Col. A. Strange and constructed by Troughton and Simms in 1869 for use in the Great Trigonometrical Survey of India. By means of this and a somewhat improved instrument of similar design and make, many latitudes were determined in India during the period 1884–1900; from 1890, however, a more convenient zenith telescope has been mostly employed in India for determining latitudes by Talcott's method.

The instrument illustrated consists of a telescope of 4-in. aperture and 48-in. focal length, mounted rigidly upon a double sector which forms part of a graduated vertical circle of 3 ft. diam. The telescope can rotate upon a horizontal axis supported by a vertical metal pillar, and the vertical rotation is measured by means of four microscopes fixed to the frame carrying the axis. The instrument can be accurately adjusted upon its base frame so that the vertical sector revolves in the meridian plane, and its zero line is adjusted to be horizontal by means of a sensitive spirit level; the zero line is perpendicular to the telescope axis of sight, which therefore points to the zenith when the former is horizontal.

The sector is graduated on silver every 5′; each limb extends over 55° and is read by two microscopes, separated 20° from each other, to single seconds; a separate smaller microscope serves to read degrees and minutes on the sector graduations.

The telescope has a micrometer eyepiece fitted with a diagonal reflecting prism. A setting circle, of diameter 8 in., divided to 10′ and read by vernier to 10″, is mounted on the telescope near its eyepiece, and is provided with a small level and also a very sensitive one, which latter permits the instrument to be used as a zenith telescope for observations by Talcott's method. The probable error of latitude determination with this instrument was about 0·05″.

(*See* "Great Trigonometrical Survey of India," Vol. XI, 1890.)

Inv. 1883–14.

226. PHOTOGRAPH OF ZENITH TELESCOPE (3-in.). Lent by T. Cooke & Sons, Ltd.

This photograph illustrates a 3-in. portable zenith telescope for determining latitudes by the Talcott method. The original instrument was supplied to the Survey of India in 1909, and is a typical example of the modern zenith instrument for geodetic work.

The telescope, of 3-in. aperture and about 42-in. focal length, is mounted at one end of the horizontal axis by means of a centrepiece, which also carries the Talcott level frame. The latter has two chambered levels, running 0·1 in. to 2″ of arc, enclosed in special sealed cases lined with thermal insulating material, and is provided with a long sensitive clamp and slow motion screw permitting an accurate adjustment in altitude. The horizontal axis has a weight relieving spring and ball race at the telescope end and a counterpoise at the other end; it is hollow to permit illumination of the telescope field by means of an oil or electric lamp. The telescope has a steel micrometer eyepiece, giving a value of about 50″ to one revolution of the micrometer screw. A 7-in. setting circle, divided on silver to 30′ and reading by vernier to 1′, is mounted on the telescope near the eyepiece end.

A 10 in. diam. horizontal circle, divided on silver to 30′ and read by vernier to 1′, is mounted on the tribrach base, which is provided with three levelling footscrews. A clamp and slow motion screw controls the vertical axis motion, and two adjustable stops are provided to enable the telescope to be rapidly rotated in azimuth through 180°.

A striding level is mounted above the horizontal axis of the instrument.

Inv. 1921–513.

227. PORTABLE TRANSIT. Made by Brauer, Pulkowa Observatory. Lent by the Royal Observatory, Greenwich. Plate VI, Fig. 2, p. 86.

A transit of this type was used about 1850 by F. G. Struve in his measurement of an arc of the 52nd parallel from Haverfordwest to Eastern Russia.

The telescope has a 2·7 in. objective and is "broken" where it meets the hollow transit axis, a diagonal prism being here interposed to deflect the light into the eyepiece tube at one end of this axis. The diaphragm of the Ramsden eyepiece, which has a pair of movable wires actuated by a micrometer screw in addition to an adjustable reticule, is illuminated by a lamp mounted at the other end of the transit axis. A vertical circle of 11 in. diam., divided on silver to 10′, is fixed to the transit axis near the eyepiece, and is read by an index on the adjacent standard. The steel pivots of the transit axis rest on high standards projecting from the levelling platform, which is supported on the wooden tripod stand by three levelling screws, having a point, line and plane contact respectively with the bearing plates. Two small bubble-levels are used to set the base horizontal by means of the footscrews, and the transit axis is finally adjusted horizontal by a sensitive hanging level.

The telescope can be lifted from its bearings on the standards and reversed end for end by means of a rotating framework mounted inside the levelling platform and carrying two extending forks which support the transit axis during the rotation. Inv. 1914–304. S.M. 1941 & 1942.

228. PHOTOGRAPH OF TRANSIT INSTRUMENT (3-in.). Lent by T. Cooke & Sons, Ltd.

Transit instruments of the type here illustrated are sufficiently portable to be used for time and longitude observations in geodetic surveys. Transits very similar to the original of this photograph have been supplied to the Colonies in recent years.

The telescope, of 3-in. aperture and about 36-in. focal length, has two setting circles of 6 in. diam., reading by verniers to 20″, mounted near its eyepiece end, and is mounted upon a rigid horizontal axis fitted with a long clamp and slow-motion screw. The axis rests in bearings upon a massive U-shaped frame which permits the telescope to transit, and also carries a mechanism for lifting the telescope axis from its pivots and reversing it through 180° in azimuth. The supporting frame is adjustably mounted upon a base plate which can be fixed on a masonry pier.

The diaphragm of the telescope is of glass and has seven lines ; it is illuminated through the transit axis by means of an electric lamp at one end of the latter. A sensitive striding level is mounted above the axis. Levels, tangent and slow motion screws are fitted to both setting circles. Inv. 1921–514.

229. EQUAL ALTITUDE INSTRUMENT. Made by A. Jobin, Paris. Plate VII, Fig. 1, p. 90.

This instrument, also known as a " Prismatic Astrolabe," was designed by MM. Claude and Driencourt about the year 1900, and is used for the astronomical determination of latitude, local time and azimuth. It acts on the principle of determining the exact moment at which a known star crosses a horizontal circle of constant angle, namely 60°.

The instrument exhibited is the " geodetic " model of the firm, and has a telescope of aperture 40 mm. and magnification 75 diam. Latitudes can be determined with it to 0·4″ and time to $\frac{0\cdot04}{\sin\lambda}$ sec., where λ is the co-latitude of the observing station.

The telescope can rotate in azimuth upon one end of a horizontal plate, which carries a mercury artificial horizon at its other end and can itself rotate above the graduated horizontal circle of the instrument. This circle is divided in degrees, and enables the telescope to be set approximately in the desired azimuth for observing any particular star.

An equilateral glass prism of sides and height 45 mm. is mounted in front of the objective lens of the telescope, with its base vertical and apex edge horizontal. When the star is nearly at an altitude of 60°, two images are seen of it in the telescope, one by light refracted through the prism and telescope, and the other by light reflected from the mercury horizon before refraction in the prism. At the precise moment that the star crosses the 60° horizontal circle, the two images meet on the same horizontal line of the telescope graticule.

By a series of similar observations of the times of crossing of known stars, both latitude and local time can be ascertained from tables.

(*See* " Handbook of the Prismatic Astrolabe," by J. Ball and H. Knox-Shaw, 1919.) Inv. 1920–131. S.M. 1939 & 1940.

MINE SURVEYING.

Underground surveys, made in the confined space of mine shafts and galleries, are usually effected by the method of traversing rarely employed above ground for precise work. The magnetic needle has always been a favourite instrument for use in traversing, and we find it adapted to mine-surveying in the earliest known treatize on mining, Agricola's " De Re Metallica," published in 1556. This book shows

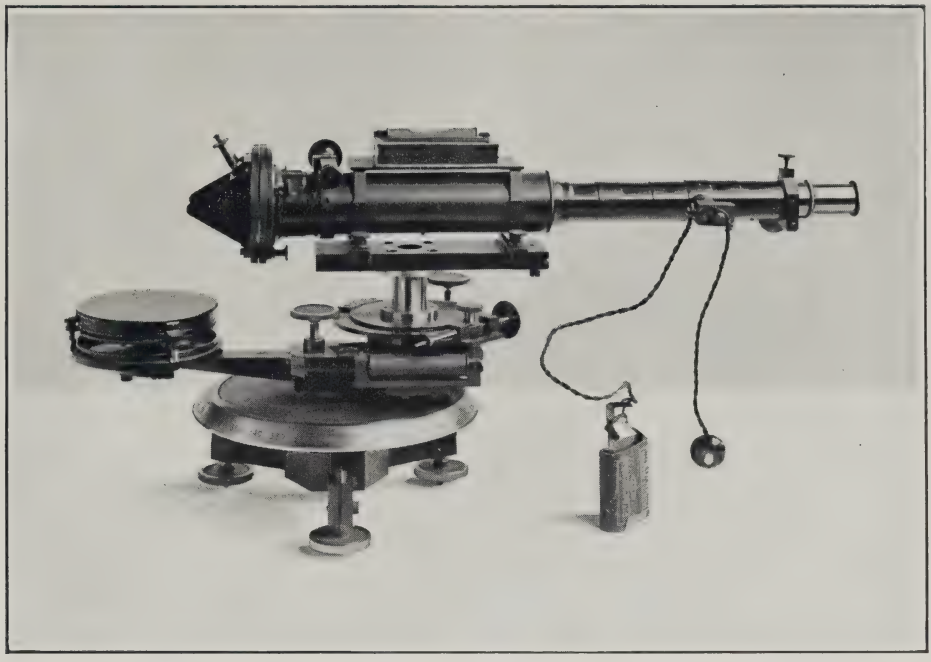

Fig. 1. Equal Altitude Instrument, by Jobin, p. 90.

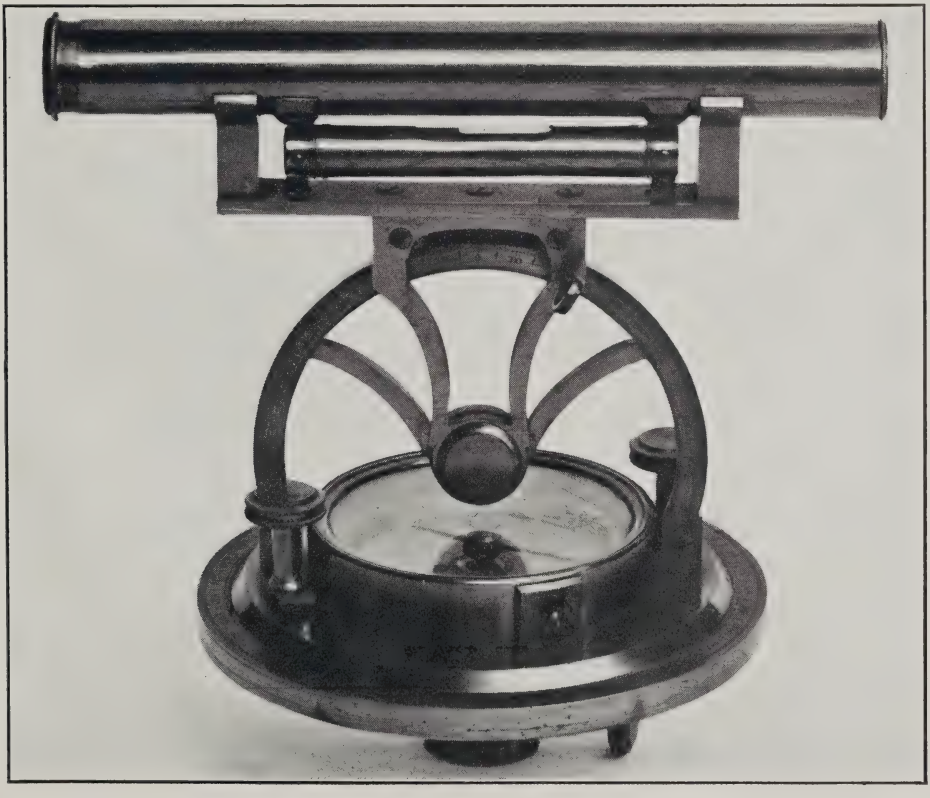

Fig. 2. Lean's Dial, by W. & S. Jones, p.92.

a species of plane-table compass, the early German "setz-compass," in which the compass box is mounted within a rotatable tablet provided with several concentric rings of differently coloured wax and a rotating ruler. The compass has no graduations beyond an index mark, above which the needle was made to set by rotating the tablet, after which the line joining the observing station to the next one was marked upon one of the wax rings by means of the ruler. No sights were employed, but the stations were connected by a stretched, knotted cord, which served both to measure the intervening distance and to indicate the direction in which the ruler must point. A mine compass of this type, dated 1541, is preserved in the Clausthal School of Mines. At this period the underground survey results were plotted upon the surface, full scale, principally to see how near the tunnels had been driven to the boundaries of the concession.

The magnetic compass continued in use for mine surveying, both on the Continent and in England, until the middle of the 19th century, and is still employed in minor work. In Germany, "hanging" compasses and clinometers were used to measure the bearing and inclination of the cord or chain stretched between successive stations of the traverse. A compass of this type, suspended in a gimbal mounting, was invented by Roessler and first described in Voigtel's "Geometria Subterranea," 1686. An improved pattern, known as the "Freiburg hanging compass," was introduced by the Freiburg instrument-maker, Studer, about 1810. In England the compass was provided with a graduated circle and a vernier sight-rule during the 18th century, at the end of which the telescopic type, fitted with a vertical graduated arc, known as Lean's Dial, was introduced (*see* No. 230). Many surveyors, however, still used the plain Miner's Dial (*see* No. 231), with sight-rule, the compass being mounted upon a swivel joint which allowed its plane to be set vertical, when inclinations could be measured upon the compass lid, which was fitted as a plummet clinometer. In 1850 John Hedley brought out the improved dial known by his name; this had the sight-rule fixed upon a rocker frame pivoted to the compass box, so that steep sights could be taken without disturbing the compass (*see* No. 232). A vertical arc could be attached to the rocking frame and the position of an index fixed to the compass could be read off on this arc to measure altitude angles. The Hedley dial, provided with vernier arc and supplementary telescope to replace the sight-rule, has always been popular in England.

Modern investigations of terrestrial magnetism have, however, established the uncertainty of traverses depending upon the magnetic needle, and the custom has arisen of employing a dial fitted with outside verniers attached to the telescope, or using a special kind of theodolite, so that the angles could be measured as in surface surveys. For this type of traverse, the instrument has to be accurately centred over the observing station point, so that modern mining theodolites are usually provided with some type of shifting centre to permit this adjustment to be made. In the best class of work, it is also customary to have special targets, which can be mounted upon the same tribrach stage as the theodolite so that target and theodolite can be interchanged as the survey progresses. Provision is made for illuminating the target and theodolite cross wires.

In order to connect up the underground survey with the surface network, it is necessary to fix either a single point or a single line of one survey with respect to the other. For this purpose, special plumb-

lines, made of wire, may be used. A heavy plummet is attached to this line and allowed to swing freely ; its oscillations may be damped by vanes moving in water. The position of the line is measured above ground by the theodolite in the normal manner and below ground by observing the oscillations and deducing the mean position, for which purpose the eyepiece of the telescope may be fitted with a special scale, or such a scale may be fixed beside the swinging plumb-line and observed through the telescope. Where it is necessary to fix a line, not merely a point, it is usual to employ a transit theodolite to sweep out this line. The ordinary mining theodolite can be adapted for this purpose by providing it with a supplementary telescope mounted above or at the side of the ordinary one, so that vertical sights can be taken. Another method often used is to set out the underground and surface lines by means of a delicate magnetic needle (*see* No. 237), but great care is necessary if the readings of the needle above and below ground are to be reliable.

230. LEAN'S DIAL. Made by W. & S. Jones. Plate VII, Fig. 2, p. 90.

In this instrument, made in the early part of the 19th century, the vertical semicircle is fixed to the alidade with its curved edge upwards, and the telescope rotates tangentially upon it. This arrangement permits nearly vertical sights to be taken and renders the instrument suitable for mine surveying. The vertical arc and telescope can easily be detached from the alidade for packing the instrument.

The horizontal circle has a diameter of 4 in. and is graduated in degrees. The vertical arc has a diameter of $3\frac{1}{2}$ in. and is graduated in degrees on one side. On the other side is a scale of corresponding hypotenuse increments. Both circles read by vernier to 5′, but have no slow-motion fittings. The alidade also carries a compass box with a 2 in. ring, graduated in degrees.

The telescope has a focal length of 5 in., a clear aperture of 0·5 in., and a simple inverting eyepiece with a cross-thread diaphragm. There is no focussing arrangement. A spirit level is mounted in adjustable bearings beneath the telescope.

(*See* "Geometrical and Graphical Essays," by G. Adams, 1813, p. 231.)

Inv. 1908--120. S.M. 2197.

231. MINER'S DIAL. Made by Henry Barrow & Co.

The plain mine surveyor's dial is very similar to the old circumferentor and has been much employed in England owing to its adaptability to surveying in low galleries and suitability for traversing. The instrument exhibited is a mid-19th-century dial, with a 5-in. compass ring graduated in degrees and a vernier fixed to the movable alidade reading to 3′.

The compass ring and base are mounted upon an axial socket perpendicular to their planes and can be rotated about the central axis which fits in this socket and terminates in a spherical ball. This latter is gripped by another socket and can be clamped in any desired position so that the plane of the compass faces any direction. A slit in the socket allows the compass to take up a vertical position for measuring altitude angles. When measuring azimuth angles, the plane of the compass is levelled by means of a pair of perpendicular tube spirit levels fixed to the alidade. This is attached to the compass case, and carries combined backsights and foresights at each end. The alidade and compass case, with the internal vernier scale can be rotated independently of the compass ring and angles measured as in a theodolite, or the case can be clamped to the compass ring and the two rotated together about the axis of the latter for taking magnetic bearings, as in the ordinary compass. In the former case, the alidade is fitted with a tangent screw for slow-motion adjustment.

The sights are 6 in. high and fixed at a distance of 1 ft. apart on the alidade. Each sight has both a slit and a pin-hole backsight and a long single-wire and a cross-wire foresight. The aperture and cross-wire sights are for use in measuring altitude angles. For this purpose the compass needle is locked by operating the lifting lever, the plane of the compass is set vertical, and the lid is placed in position on the box, and a plumb-line suspended from a stud in this lid. The opposite edge of the lid is graduated in degrees up to 45° each way and has a scale of hypotenusal increments engraved on it. Inv. 1907–66.

232. HEDLEY DIAL. Made by B. J. Hall & Co., Ltd.

The chief feature of this mining dial, which is a modern example of the type invented by John Hedley in 1850, is the use of a rocking circle, pivoted externally on horizontal bearings to the compass box, to carry either plain sights or a telescope. This arrangement permits a fairly steep vertical angle to be measured, the angle being read by an index revolving with the rocking circle over a graduated semicircle fixed to the compass box. The compass ring can rotate inside the box about the vertical axis, for measuring azimuth angles independently of the needle, or can be clamped to the box for taking magnetic bearings.

The compass ring has an outside diameter of 5 in. graduated in degrees for reading with the vernier, which is fixed to the box above one pivot of the rocking circle. The graduations extend to the inner edge of the ring, which has a diameter of $4\frac{1}{4}$ in. and is read by the needle. The base of the compass is also graduated every 10° and the cardinal points are marked on it. It also carries two spirit levels with their axes mutually perpendicular.

The vertical semicircle has a diameter of 5 in. and is graduated in degrees, with an inner scale of hypotenusal increments. The rocking circle has projecting lugs at right angles to its axis of rotation. The plain sights or standards for the telescope can be fixed to these lugs. The plain sights are 6 in. high and have both slits and wires for taking azimuth angles either way. In addition, one sight has a pin-hole aperture and the other a pair of cross wires for measuring vertical angles. The telescope has a rack-focussing objective, of focal length 9·5 in. and aperture 1 in., a simple cross-wire diaphragm, and a slide-focussing inverting eyepiece. It carries a sensitive spirit level fixed to it by adjustable bearings. The compass ring, which has a tangent clamp and slow-motion screw, reads by vernier to 3′. The compass box and upper part can rotate about a vertical axis and can be fixed by a tangent clamp. The socket is threaded to fit a pair of parallel plates for levelling. Inv. 1922–43.

233. MINING THEODOLITE. Made by F. W. Breithaupt & Son, Cassel.

Theodolites with eccentrically mounted telescopes and vertical circles, which can be transited without requiring high standards projecting from the horizontal vernier plate, have been very generally employed by Continental mine surveyors owing to their suitability for work in low galleries. The example exhibited is of this type, the transit axis being mounted just above the vernier plate and carrying a telescope and vertical circle at one end, just clear of the horizontal circle. Both circles are of 3-in. diam., graduated every 30′ and read to 1′ by opposing verniers. A 3-in. compass, mounted upon a large circular spirit level, is fixed to the upper part above the transit axis.

The horizontal circle and vernier plate have independent vertical axes of rotation for repeating azimuth angles, with separate clamps and tangent screws. The axial socket of the circle carries a tribrach fitted with levelling footscrews. The feet of these rest in small footplates, as is commonly the case in German instruments of this period—the latter half of the 19th century. The footplates rested on the tripod head, which was connected to the instrument by a central plunger screw. On loosening this, the theodolite could be accurately centred without moving the tripod.

A stout tubular supporting piece projects centrally above the vernier plate and carries the socket for the transit axis, and the ring for the compass and spirit level. The vertical circle is fixed to the transit axis socket and the telescope to an inner rotating vernier plate, which also carries a tangent clamp and slow-motion screw fitting. A spirit level is mounted on the telescope, parallel to the line of sight. The telescope has a fixed objective of $\frac{3}{4}$-in. aperture and a rack-focussing eyepiece tube carrying a fixed Huygens ocular, with a pair of cross wires fixed between the two lenses. A diagonal reflecting prism is screwed to the eyepiece for convenience in sighting. The compass ring is graduated in half-degrees, and a lifting lever is provided for clamping the needle against the cover, the glass cover of the circular spirit level forms the base of the compass box.
Inv. 1876–1197.

234. RAND MODEL MINING THEODOLITE. Made and lent by T. Cooke & Sons, Ltd., York.

The special features of a modern mining theodolite are well illustrated in this example, of which the chief characteristics are the protection of all delicate

parts from the dust and dirt inseparable from mine surveying, and the provision of means for taking sights at very short ranges and at extreme vertical angles.

The 4·5-in. horizontal and 4-in. vertical circles are graduated directly to 20′ and read by two opposing verniers and reading microscopes to 30″. Both circles are encased in metal, the verniers being protected by hinged glass covers, which can be raised for cleaning. The circles and the horizontal vernier plate have independent motions, and are provided with clamping and slow-motion screws, the two screws to each circle being distinguished by differently shaped heads. All the verniers have ground glass reflectors.

The main telescope, of 6·5-in. focal length and 1·1-in. aperture, transits at either end, and has an internal focussing lens actuated by a screw at one end of the transit axis. This arrangement permits the telescope tube to be rendered dustproof, and to be focussed down to 5 ft. An objective focussing auxiliary telescope, of 5-in. focal length and 0·9-in. aperture, can be fitted either on top or at the side of the main telescope, for use in taking steep sights, and is balanced by a counterpoise. Both telescopes and reading microscopes have screw-focussing inverting eyepieces. An additional diagonal erecting eyepiece is provided for use with either telescope. The diaphragm of the main telescope is of the web type, with 1 : 100 horizontal stadia lines, and can be readily withdrawn for repairs. An interchangeable glass diaphragm is also supplied.

The standards supporting the vertical circle and telescope axis are fixed to the vernier plate, which carries a small circular spirit level and a long adjustable tubular one, with its axis parallel to the transit axis. A similar tubular level is mounted upon the telescope, and can be adjusted parallel to its optical axis. The horizontal circle is attached to a tribrach, in the arms of which three foot-screws engage. The screws are provided with dustproof covers, and their feet are firmly fixed in a trivet stage, which can be screwed to the tripod head but has also three pointed feet for fixing it upon a platform independently of the tripod. The tripod head has a centring arrangement of 2¼-in. range, permitting the instrument to be centred over the station point without moving the tripod legs.

A delicate compass of special design is attached to one standard and serves to give a magnetic zero line. Inv. 1921–558.

235. BRUNTON MINING TRANSIT. Made and lent by C. F. Casella & Co., Ltd.

This so-called transit is essentially a combined compass and clinometer designed for filling in the minor details of a survey, more particularly in mine surveying, as the sights can be adjusted to steep slopes without displacing the compass box from the horizontal. The position of the compass needle and the bubble of the clinometer can be read at the same time as the sight is taken by means of the mirror mounted inside the hinged lid of the compass box.

The instrument consists of a circular aluminium compass box, to which are attached on opposite sides a hinged lid and a hinged slit and aperture backsight. The inner face of the lid is a mirror and has a diametral line engraved upon it, which bisects an aperture pierced in the lid near the hinge ; this aperture serves as foresight for viewing any object, though the reflection of the slit of the backsight in the mirror, together with the line engraved thereon, serve to determine the exact bisection of the object viewed. In taking sights, the lid is inclined at an angle of 45° to the face of the compass, so that a reflected image of the compass ring and clinometer is seen.

The compass has a stepped ring, about 2¼-in. diam., with its edge graduated in degrees. An edge-bar needle is pivoted at the centre and can be lifted from the pivot by means of a lever, actuated by pressing a button. The act of closing the lid of the compass depresses this button and clamps the needle. The clinometer arrangement is pivoted to the base of the compass below the needle and consists of a rotatable vernier arm upon which is mounted a small bubble level. The arm traverses a graduated arc engraved on the base of the box, and the vernier reads this arc to 10′. The movement of the arc is operated from outside the box by means of a small rotating arm having a milled button at its extremity. Two flats are filed upon the side of the compass box, which is rested on either of these when vertical angles are being measured by means of the clinometer.

The aperture plate of the backsight bracket is separately hinged to this, so that, when the bracket is adjusted to the angle convenient for taking a sight, the aperture plate can remain vertical. Inv. 1924–465.

236. MINER'S DIAL. Made and lent by Messrs. Cooke, Troughton & Simms, Ltd.

The requirements of minor and routine mine surveying, particularly in collieries, can often be met by a dial of this type, which has recently been designed by the makers to replace their Rand Model Mining Theodolite (*see* No. 234), where particular accuracy is not a necessity. A special feature of the dial exhibited is the sighting arrangement which is claimed to afford the advantages of open sights without the focussing difficulties of the latter.

The compass box, mounted upon the tripod head by means of a ball and socket levelling arrangement, is designed for loose or fixed needle reading. It has a 5-in. horizontal circle, graduated in degrees, numbered 0–360° clockwise and read by opposing verniers to 1′, and a needle circle also graduated in degrees, numbered 0–360° in the anti-clockwise sense. The readings of the two circles thus correspond and may be checked by comparison. The horizontal circle is provided with a clamp and slow-motion screw, whilst the compass box as a whole can be clamped to the base. The needle is 4·25 in. long and is mounted freely upon a steel pivot; it is provided with a lifting and clamping arrangement, designed to prevent shocks.

Upon the rim of the compass box is pivoted a solid arm, carrying at its outer end the vertical circle with the sighting tube fixed thereto. The circle can rotate upon a horizontal axis in the arm, to which a vernier bracket is attached for reading the circle to 6′. The circle is of 3-in. diam., and is protected by a metal guard.

The sighting tube is provided with a simple optical system of unit magnification, whereby the image of the target is brought into the same plane as the reference mark, which is a point or cross wires engraved on a glass diaphragm. The line of sight is above the centre of the compass box, and the supporting arm can be adjusted to enable vertical sights to be taken.

(*See* "The Colliery Guardian," July 27th, 1923.) Inv. 1925–3.

237. MINE MAGNETOMETER. Made and lent by Messrs. Cooke, Troughton & Simms, Ltd.

Many mining surveys, being based upon magnetic bearings, require an accurate determination of the magnetic meridian to serve as a periodical check and to connect them with the surface survey. The ordinary magnetic needle is not sufficiently sensitive to respond to the daily changes in the magnetic meridian, and the instrument exhibited was designed by Mr. T. Lindsay Galloway to enable the meridian to be fixed with the required accuracy.

The instrument consists of a tribrach levelling stage, supporting a long cylindrical case within which is suspended an arrangement consisting of a plane mirror and a pendant connected by a fibre of unspun silk. Both mirror and pendant are mounted upon stems to which the ends of the fibre are fixed, and a small bar magnet is attached across the back of the mirror. Either the pendant stem or the mirror stem, or both together, can be clamped to the case by means of adjustable stirrup clamps, and the case can be inverted upon the tribrach levelling stage so that either the pendant or the mirror is uppermost.

In using the instrument the case is first set up with the mirror above and the pendant below, and the latter is then unclamped and allowed to turn freely until it comes to rest, when it is clamped up again. By this means any twist is taken out of the fibre. The case is next inverted so that the mirror is below the pendant, and the mirror is unclamped, whereupon it oscillates between two stops. If necessary, the case is rotated in azimuth to enable the mirror to come to rest with its plane in the magnetic meridian. If now a theodolite is directed on the mirror and adjusted until it centres the reflected image of a plummet suspended below its own axis, the line of sight will be perpendicular to the meridian.

This type of magnetometer is now obsolete.

(*See* "A Method of Determining the Magnetic Meridian," by T. Lindsay Galloway, Trans. Institute of Mining Surveyors, Vol. LVI, Part 4.)

Inv. 1925–8.

MARINE SURVEYING.

Information regarding the relative positions of various coastal features, depth of water, and similar data of importance to navigators, must have been sedulously collected and compared by early mariners, and it is significant that the Alexandrian geographer, Ptolemy, relied

largely upon the statements of his predecessor, Marinus of Tyre, for the data which enabled him to construct his maps. Marinus had himself constructed a map based upon his voyages. Four centuries previously, Pytheas of Marseilles, a contemporary of Alexander the Great, had made important observations of the shores of Gaul and Britain. These early navigators relied largely for their estimates of relative positions upon observations of the comparative lengths of the day between sunrise and sunset and records of the number of days required to sail between various points, but occasionally checked their estimates by erecting sundials at the places visited by them and determining the latitude by this means. It is significant of the early development of marine surveying that in all early maps the Mediterranean coast districts are comparatively accurately delineated.

Similarly, during the late Middle Ages and Renaissance periods, the portolanos or nautical charts exhibited a marked superiority over the existing land maps; this was probably due to the fact that navigators were equipped with portable astrolabes, quadrants or cross-staffs for estimating latitudes, and with magnetic compasses for determining directions. The first arc measurement made in England, by Richard Norwood in 1633, was more related to hydrographical than to land surveying, for Norwood was the author of a work on navigation, and his object was to ascertain the length of a degree for the purpose of correcting the nautical charts then extant.

With the invention of the back-staff by John Davis about 1594 and Newton's reflecting octant a century later, the marine surveyor became better equipped with instruments for measuring celestial and terrestrial angles. Finally, in 1731, Hadley published the account of his new reflecting octant, which was a great improvement upon any existing nautical observing instrument, and required few modifications to transform it into the modern sextant. This instrument, provided with tangent screw, telescope and vernier scale, enabled the navigator to determine his latitude very accurately, and was equally well adapted for coast surveying by triangulation. In 1733 Hadley added a spirit level to his octant to define the horizontal when the natural horizon was obscured by fog or by darkness, but the attempt to provide a nautical sextant with an artificial horizon for use at sea has never attained much success.

The main difficulty of determining the ship's position astronomically has always lain in the comparative inaccuracy with which longitudes could be obtained. For long, mariners had to rely upon dead reckoning for this purpose. Attempts were made during the 17th and 18th centuries to utilize the variation of the magnetic declination and observations of lunar phenomena or stellar occultations as means of ascertaining the longitude, but the problem was not solved successfully until John Harrison, in 1735 and the subsequent years, devised a method of compensating the temperature variations of watches and thus originated the chronometer, which enabled standard time to be maintained throughout a voyage. Local time could always be determined by means of the sextant. Harrison's invention consisted in the application of a bi-metallic compensating device to watches.

With the invention of the sextant and chronometer, marine surveying was put upon the same accurate basis as land surveying had been by the development of the theodolite, and the era of modern

hydrography begun. In 1795 the Admiralty Hydrographic Department was founded for coast and harbour surveying around Great Britain, and similar activities were inaugurated on the Continent at the same period.

For coast surveying on shore the sextant was often employed, but modern hydrographic surveyors have favoured the use of the theodolite for onshore work. For taking angles from the sea, the sextant remains the most suitable instrument. Attempts have been made to increase its angular range by means of suitably disposed reflectors, and to substitute a complete graduated circle for the sextant, whilst the superior rigidity of reflecting prisms has induced some makers to substitute these for the ordinary mirrors.

In many respects, hydrographical surveying is merely a repetition of land surveying, but it differs principally in the use of the sextant owing to the usual instability of the observing station, and the more frequent employment of the method of resection ; in this method the position of the observing station is fixed by angular observations upon three fixed points, and plotted by means of the station pointer. Also, to contour the sea bottom, special sounding appliances are necessary, and in this connection hydrography owes much to the genius of Lord Kelvin.

238. SEXTANT. Made and lent by F. Newton & Co.

This is a sextant of the usual type employed in marine surveying. It has a graduated arc of 8-in. radius, divided on silver to 10′ and read by vernier and magnifier to 10″. The arc extends from 0° to 150°, each numbered degree being really only half a degree.

The vernier moves with the index arm, which is pivoted at the centre of the arc and carries the index mirror. A long telescope is mounted in the usual up and down piece on one outer radius of the arc and faces the horizon mirror, mounted on the other outer radius. Coloured glasses are provided for astronomical sights, and a handgrip is mounted on the under side of the frame. Inv. 1865–6.

239. SEXTANT. Made by H. Haecke, Berlin. Presented by the Admiralty.

This sextant is believed to have belonged to the German surveying ship "Moewe." It is of the usual construction and has an arc of radius 20 cm., divided to 30′ and read by vernier to 1′.

The index arm, carrying the index mirror at its centre and the vernier at its extremity, is provided with a clamp and tangent screw for slow motion. Coloured glasses are fitted on pivots near both mirrors. A handgrip fixed beneath the frame is used when taking vertical angles, and has a screw socket beneath it for attaching a perpendicular handgrip used for taking horizontal angles. The telescope has two erecting eyepieces, of magnification 3 and 4 diam. respectively. A plain sight tube is also provided. The telescope supporting ring can be elevated or depressed by a fine screw in the usual manner. Inv. 1920–84.

240. REFLECTING CIRCLE SEXTANT. Made by Pistor & Martins, Berlin. Lent by the Admiralty.

This instrument, which was salved from a German warship sunk at Scapa, has a complete graduated circle instead of a sextant, and a totally reflecting right-angled prism instead of the usual horizon mirror ; it is of the type first made by Pistor and Martins in 1845. The sustitution of the prism for the horizon mirror enables angles up to 180° to be taken and also gives a clearer image at extreme angles, whilst the use of a complete circle and an index arm fitted with two opposing verniers, minimizes errors due to inequalities of graduation or inaccuracy in centring the index mirror and arm.

The circle has a diameter of 13 cm. and is graduated to 10′, corresponding to 20′ of the angle measured. This angle is read by the vernier to 20″. Only part of the graduations, namely, those under one vernier, are numbered and in these

a gap is left where the telescope and head of the observer foul the line of sight of the index mirror. This latter has its plane inclined at about 20° to the zeros of the index arm to which it is attached. The horizon prism is mounted with its reflecting face parallel to the index mirror when the verniers are at zero. It is opposite the lower half of the telescope, which is mounted in the usual " up and down " piece, the upper half of the field being left free from direct vision. The index arm has the usual clamp and tangent screw at one extremity, and a wooden handgrip for holding the instrument is attached beneath the circle. A reading microscope is fixed to a rotating bracket for magnifying the scales, and a set of smoked glasses for varying the illumination of the telescope field is attached to a rotating pivot near the supporting ring. Inv. 1920–89.

241. STATION KEEPERS (Bell Type). Presented by the Admiralty.

The station keeper is an instrument enabling an observer to keep himself at a fixed distance from another object, *e.g.*, an observer in a boat from his ship, by keeping constant the angle which a known length on the distant object subtends at his position.

In this type of station keeper, of which three examples are exhibited, a small glass prism of very small apex angle is mounted in a holder. The observer holds this at arm's length and views the distant fixed length partly through the prism and partly directly. If the direct sight of one extremity of the known length coincides with the image of the other extremity after refraction through the prism, his distance from the object must be invariable. The actual distance will depend upon the fixed length and the apex angle of the prism.

Inv. 1911–172.

242. STATION KEEPER (Wharton Type). Presented by the Admiralty.

This type of station keeper is essentially similar in construction to a box sextant, having a graduated arc of 6-in. radius extending over 20°. By measuring on this arc the angle subtended at his position by a fixed length on the distant object, the observer can calculate his distance from that object, or, having calculated the necessary angle, can set it on the instrument and keep his distance constant.

The instrument consists of a sector-shaped box having its wider end open and its narrower end closed, save for a pin-hole aperture for sighting. At the open end, within the box, is mounted a fixed " horizon " mirror, whilst a movable index mirror is pivoted near the closed end and geared to an external rotating index arm, which moves over a graduated arc on the upper face of the box. The gearing is done by rack and pinion gear, which causes the index arm to rotate through twice the angle through which the index mirror moves. The arc is graduated in half-degrees from 0° to 20° and the index arm carries a vernier reading to 5′.

In using the instrument the observer sights one end of the distant base directly through the space below the horizon mirror, and the other end by double reflection at the two mirrors, and moves his position or the index arm until the two ends appear coincident. Inv. 1911–173.

243. STATION POINTER. Made by H. Haecke. Lent by the Admiralty.

The arms of a station pointer are often fitted with sights which permit the instrument to act as a theodolite and thus to measure the angles subtended by three known points at the observing station. On detaching the arm piece from the circle and applying it to the chart like an ordinary station pointer, the position of the observing station can be plotted. The instrument exhibited is of this combination type, and was salved from a German warship sunk at Scapa Flow.

It has a graduated circle of 11-in. diam., with its edge divided on German silver to single degrees. This circular plate can rotate within a hollow central axis which terminates below in a spherical ball; this ball forms part of a ball and socket joint connecting the instrument to a stand. The plate can thus be set in any plane and clamped by means of a threaded collar acting on the joint; it can then be rotated in this plane and clamped by a radial screw threaded in its outer axis and impinging on its inner one. The arms of the instrument are mounted on a separate circular ring which has a central pin fitting within a hole in the centre of the plate. Each arm is pivoted round this pin and can be turned

about it and clamped to the edge of the circular ring when the arm is directed towards the corresponding fixed point. The central pin acts as backsight for the observation, whilst each arm has a folding slit foresight fixed at its outer end. The subtended angles can then be read off on the graduated circle if required and the arm piece removed and applied to the chart. The bevelled edges of the arms are then made to pass through the corresponding fixed points on the chart, when the central pin marks the position of the observing point. This pin is mounted loosely in the arm piece and its point kept slightly above the plane of the arms by a spring. On depressing the head of the pin, its point makes an indentation in the chart and thus plots the position of the observing station.

The arms are 14 in. long from central pin to sights, but can be extended to 20 in. by means of the three extension pieces shown. Two of the bevelled edges can be brought to coincide, but the third cannot be set less than 14° from the other two. Inv. 1920–22.

244. NORDENFELT SEXTANT. Presented by C. F. Casella & Co., Ltd.

This modified form of sextant was designed by T. Nordenfelt about 1884 for rangefinding at sea. Observations are taken with the plane of the sextant vertical from a point on board ship at a known height above sea level upon the water line of a distant object and simultaneously upon the horizon. When the horizon and water line images are made to coincide by revolving the index arm, the reading of the index on the graduated arc gives the range of the distant object directly.

The index mirror is not mounted upon the pivot of the rotating arm, but upon an eccentric pivot, connected to the arm by a cam and pin mechanism, which causes the mirror to rotate through a much smaller angle than the arm; this enables the angle swept out by the reflected ray to be varied very gradually between narrow limits, whilst the index traverses an arc of 60° or thereabouts. As the angle of depression of the distant object below the horizon varies inversely as the range, if the base—*i.e.* the height of the observer above sea level—is constant, the arc of the sextant can be graduated to read the range directly. Different arcs are, however, necessary for different observing heights, and three are provided, two for heights of 96 ft. and the third for a height of 47 ft.; any arc can be fixed in the sextant frame by means of clamping pins.

The effect of the dip of the horizon is allowed for on the graduated arcs. The rotating arm is provided with one fixed index mark and another index which can be displaced relative to the fixed one by means of a tangent screw; the arm has a separate clamp and tangent screw. Two telescopes, of different fields and magnifications, are provided.

(*See* British Patent Specification No. 16029 of 1884.) Inv. 1923–405.

PHOTOGRAPHIC SURVEYING.

Although perspective sketches have been employed for many centuries, and their theory studied by various geometricians such as Lambert, it was not until the end of the 18th century that an attempt was made to reproduce a horizontal plan from a series of such sketches. At this period the French hydrographer Beautemps-Beaupré constructed a series of coast charts based on oriented perspective drawings, but his method found few disciples. In the middle of the 19th century the recent invention of the Daguerre photographic process led A. Laussedat to study the application of photography to surveying purposes. He developed methods and instruments for this purpose, and, under his direction, a few test surveys of small areas were made. Laussedat's methods only created a temporary interest in France, but were developed by Italian, German and Austrian engineers during the last four decades of the century. Various types of surveying cameras, or photo-theodolites, were devised by Laussedat in France, Paganini in Italy,

Meydenbauer, Finsterwalder and Koppe in Germany, Pollack and von Hubl in Austria, and Deville in Canada, and were employed in numerous branches of topographical surveying, but principally for surveys of mountainous districts. Paganini and Deville also designed plotting devices to assist in reproducing the plans from the photographs. At the beginning of the present century successful attempts were made to apply stereoscopic methods to photo-surveying. Deville in Canada made experiments with this aim in view, but the efforts of Seliger and Pulfrich in Germany, which resulted in the production by the firm of Zeiss in 1901 of the first Pulfrich stereo-comparator and a precision-phototheodolite designed for stereo-surveying (*see* Nos. 247 and 248), created a new impetus in photographic methods of survey. The stereoscopic examination of photographs greatly facilitated the recognition of prominent features upon a pair of prints, which had hitherto been one of the chief obstacles in the method, and efforts were next directed towards a mechanical process of cartographic reproduction. F. V. Thompson, working at the School of Military Engineering, Chatham, evolved in 1907 a stereo-plotter (*see* No. 249), which, in conjunction with the Pulfrich stereo-comparator, reduced the process of measuring the photographs and plotting the detail to one of a purely mechanical nature, but the stereo-autograph invented by an Austrian military engineer, von Orel, in 1908 was produced by Zeiss and is now considered the best instrument for mechanically plotting from stereograms. By means of this apparatus, not only can isolated points be rapidly plotted or measured, but contour lines or feature lines, such as rivers, hedges, etc., can be directly plotted by simply tracing over them in the stereo-photograph. An improved model of the Zeiss-von Orel stereo-autograph was produced in 1911 (*see* No. 250).

In ordinary ground photo-surveying, or photogrammetry, it is usual to employ vertical photographic plates only, but much labour has been expended in investigating the laws of inclined perspectives, which in certain situations have obvious advantages. Photography from the air is naturally more suited to the employment of horizontal or inclined plates than vertical ones. The first attempt to take photographs from the air was made by Nadar at Paris in 1858, using a captive balloon, and he suggested that such photographs could usefully be employed for making plans. The collodion plates were, however, very unsuitable for aerial photography, which languished until 1885, when Tissandier and Ducom, using gelatine plates, obtained excellent horizontal photographs of the environs of Paris and constructed a plan from these. The first comprehensive employment of aerial photographic surveying, however, was undertaken by the Japanese Army in the Manchurian campaign of 1904, and the development of the aeroplane and airship in the succeeding years has led to an increasing employment of this method of surveying, especially during war time and over mountainous districts. During the Great War, 1914–1918, much reconnaissance work was accomplished by aeroplane photography, both over country which had been well surveyed trigonometrically, and in which, therefore, many "control" points existed, and also over territory, such as Palestine, where few trigonometrical control points existed. In the latter type of survey, steadiness of flying is an essential for aerial mapping, for the data as to orientation and inclination of the photographic plate, provided by instrumental means, are often unreliable. Where a previous trigonometrical network exists for the country surveyed by aerial methods, it is usually possible to

deduce the inclination and orientation of the camera axis, and all other necessary data, from the actual negatives by the laws of inclined perspective. It is generally advantageous to "rectify" the plates, *i.e.* to produce the perspective which would have been obtained if the axis of the camera had been truly vertical; to perform this function various auxiliary appliances have been devised. These are mostly in the nature of special enlarging cameras having facilities for twisting the negative into the position relative to a horizontal plane which it had during exposure. The instrument devised by Captain Cole, of the Egyptian Survey Department, is of this type. On the Continent attention has been concentrated on the microscopical measurement of aerial photographs by the so-called "Bildmess theodolites" of Hugershoff and Pulfrich, which are designed for computing the data for photographs taken in an inclined position. The principles of stereogrammetry and autocartography have also been applied to aerial surveying by these two scientists.

245. PHOTO-THEODOLITE.

This instrument was designed for photographic surveying by Prof. E. J. Mills, F.R.S., about the year 1897. It consists of an accurately adjustable camera of nearly constant focus, fixed to the vernier plate of a 6-in. theodolite which gives the azimuth angle of the optical axis of the camera to 30″, and is provided with an ordinary parallel plate four levelling screw mounting for attachment to the tripod. The photographic plates are 5 in. by 4 in. The camera box, which is made of teak, has a pair of perpendicular spirit levels and a 2½-in. compass box attached to its top. The front consists of a brass plate mounted in horizontal and vertical slides, and adjusted in both directions by means of fine screws. It carries a centrally mounted Zeiss extreme angle (about 130°) anastigmat lens of 141-mm. focal length. The vertical and horizontal position of the lens is measurable by scales and verniers to 0·04 mm. The back of the camera can slide in the box and is moved by a twin rack and pinion arrangement, actuated by thumb wheels at each side. The focal length of the camera for any position of the back is read by a scale and vernier to 0·04 mm. The ground glass is graduated in centimetre squares, the central vertical and horizontal lines having millimetre graduations. Four triangular brass teeth are fixed in the centres of the edges of the back, and press against the front face of the plate during exposure. Their images on the plate after exposure serve to determine the horizon line and principal vertical line of the picture. The slides, twelve in number, are "single," and must be changed after each exposure. The base of the camera box has guides and screw threads for fixing it to the vernier plate of the theodolite, so that the principal point of the lens is vertically above the centre of the horizontal circle. This latter is graduated in half-degrees and read by opposing verniers to 30″. Clamps and tangent screws for fine motion are fitted to both vernier plate and horizontal circle. The instrument is levelled by means of the spirit level on top of the camera box, and the four footscrews. Inv. 1917–113.

246. PHOTO-THEODOLITE. Made by R. Lechner, Vienna. Lent by the Survey of Egypt.

In this photo-theodolite, which is of the type designed by V. Pollack for engineering surveys in mountainous districts of Austria, the camera is centrally mounted above the horizontal circle and carries the telescope and vertical circle at one side, these being counterbalanced by a weight carried on the other side. To reduce the weight, the camera box, telescope tube and support for the latter are made of aluminium.

The camera objective is a Zeiss anastigmat lens f/18 of focal length 212 cm., mounted in a movable plate which can be elevated or depressed to the extent of 5 cm. by means of a rack and pinion arrangement; the amount of elevation or depression is measured by a vernier and scale at the side of the plate. At the back of the camera box is a rectangular brass frame, 21 cm. by 15 cm., the inner edges of which are notched every centimetre. The photographic plate is pressed against this frame and the graduations are photographed round its edges; these serve to locate the principal and horizon lines on the picture and to discover

any subsequent distortion due to development. The ground glass screen which normally fits in the back of the camera has a telescopic eyepiece mounted at its centre; this eyepiece, which is pivoted on a horizontal axis, forms a central telescope with the camera lens as objective.

The horizontal circle of the instrument is divided to 30′ and reads by verniers to 1′; it is fitted with a clamp and tangent screw and carries two perpendicular bubble levels.

The vertical circle and telescope are mounted upon a curved bracket carried by the horizontal circle. The circle is divided to 30′ and read by verniers to 1′. The telescope has a rack-focussing eyepiece tube, fitted with stadia lines.

Inv. 1924–103.

247. PHOTOGRAPHS OF A ZEISS–PULFRICH PHOTO-THEODOLITE. Lent by Messrs. Carl Zeiss, Ltd.

Two views are here shown of a photo-theodolite designed by Dr. C. Pulfrich specially for use in stereo-photographic surveys. Above the camera is mounted a telescope which can sweep out a field of view perpendicular to the camera axis, so that, when the other station point of the base is sighted, the optical axis of the camera must be perpendicular to the base.

The camera box is of light metal and is mounted upon the rotatable limb of a graduated horizontal circle, which can in turn rotate within a levelling tribrach. The footscrews of the latter rest on a trivet plate, which can be clamped upon the tripod head after the vertical axis of the instrument has been centred above the station point. The camera objective is mounted in a sliding front plate and has a constant focal length of 127 mm. The plate rack takes 12 cm. by 9 cm. plates, upon which the horizon and principal vertical lines are automatically recorded during exposure.

The camera box can be detached from the tribrach by unclamping the screw which fixes the vertical axis of rotation. A similar tribrach, trivet plate and tripod is set up at the other base observing point and the camera can readily be transferred from one station to the other. In the tribrach which does not contain the camera, a signal pin can be clamped, centred above the station point, and observed from the camera station through the special telescope mounted above the camera box. This telescope has its optical axis parallel to the camera axis, but has a pentagonal prism mounted in front of its objective for deflecting the axial rays at right angles to the optical axis. The telescope fits within a sleeve rigidly fixed to the camera box, and can rotate within this sleeve about an axis coinciding with its optical axis. During this rotation it carries the deflecting prism with it, and also a vertical circle for measuring the amount of rotation. Any point viewed through the prism and telescope during this rotation must lie in the vertical plane perpendicular to the telescope axis, and therefore perpendicular to the optical axis of the camera.

To measure the length of the base, the telescope is sighted upon a horizontal rod of fixed length, which is mounted upon the tripod at the other base point, and the instrument rotated in azimuth by means of the tangent screw of the horizontal limb, which has a graduated screw-head for measuring the rotation necessary to traverse from one end of the distant rod to the other. By this means the base is measured tacheometrically. Inv. 1914–456, S.M. 910.

248. PHOTOGRAPH OF ZEISS–PULFRICH'S STEREO-COMPARATOR. Lent by Messrs. Carl Zeiss, Ltd.

The stereo-comparator is a special type of stereoscope, designed by Dr. C. Pulfrich about 1901, for measuring the relative displacement of corresponding points in the two views of an area surveyed from each end of a base, and deducing therefrom the position of the corresponding ground point with respect to the base. The position of each ground point is separately measured in terms of its azimuth, altitude and range (perpendicular to the base) from the left-hand base terminal point.

The comparator consists of a binocular telescope, very similar to a stereoscopic rangefinder, mounted above a traversing frame which carries the two negatives. Each eyepiece of the telescope carries in its focal plane a fixed index mark. When the negatives are viewed through the twin eyepieces, the observer sees a combined image of the index mark apparently suspended in space above the country surveyed, which is presented in bold relief. By operating the mechanism controlling the movements of the negative and telescope carriages the mark can be made to " touch " any point of the landscape, and the readings of the scales then give the position of that point.

The two negatives can be traversed together in a lateral direction parallel to their horizon lines by means of a rack operated by the wheel shown on the left of the instrument and known as the " direction " wheel, or the right-hand plate can be moved alone in the same direction by means of the wheel on the right-hand side of the instrument. The latter is known as the " parallax " or " distance " wheel. Each movement is registered by scales and verniers, whilst the " distance " wheel has a micrometer drum head for recording the smaller movements. The telescope can also be moved across the negative carriage in a direction parallel to the principal vertical lines of the views by means of the " height " wheel, shown in front of the middle part of the instrument, and the amount of motion measured on the " height " scale.

The instrument is originally adjusted so that the mark appears to be at an infinite distance from the observer, in a direction coinciding with that of the principal point of the negatives, *i.e.* perpendicular to the base of the survey. When the mark is made to coincide with any point of the landscape, the readings of the direction, distance and height scales give the azimuth, range and altitude of that point with respect to the left base point. All the scales read to 0·01 mm.

The instrument is designed to take negatives of dimensions 12 cm. by 9 cm., such as are used in the photo-theodolite, by Zeiss, illustrated in an adjacent photograph.

(*See* " La stéréoautogrammétrie," by P. Corbin in " Revue générale des Sciences," Vol. 25, 1914, p. 231.) Inv. 1914–456. S.M. 909.

249. PHOTOGRAPHS OF THOMPSON'S STEREO-PLOTTER. Presented by W. Watson & Sons, Ltd.

Early in 1907, Lieut. F. V. Thompson, R.E., at the School of Military Engineering designed the instrument illustrated in these two photographs for the purpose of automatically plotting the positions of points obtained by a stereo-photographic survey. The apparatus consists of a Pulfrich stereo-comparator, with a pair of plotting boards traversed by rulers connected to its measuring mechanism in such a manner that the co-ordinates of the point viewed in the comparator can be automatically plotted on the boards.

In the Pulfrich comparator the three co-ordinates of any point surveyed, namely its direction, altitude and range, are measured by the motions of the main slide, the microscope bridge slide and the parallax slide respectively. The two plotting boards of the stereo-plotter, which may be called the plan and elevation boards respectively, are provided with one common " ordinate " ruler and separate " abscissa " rulers. The two latter are geared respectively to the main slide and microscope slide mechanism of the comparator, and are moved automatically over their boards by the operation of setting the comparator on the view point. The ordinate ruler has to be set by hand at a distance from the plan point of the camera station equal to the " range " of the view point as recorded on the range drum of the comparator, which drum is operated by the mechanism of setting the parallax slide. After this setting of the ordinate ruler, its point of intersection with the abscissa ruler of the plan board gives the plan point of the view point, whilst its intersection with the abscissa ruler of the elevation board gives a reading upon a scale fixed to the ordinate ruler which registers the elevation of the view point above the camera station.

(*See* " Geographical Journal," Vol. XXXI, 1908, pp. 534–551.)
Inv. 1914–297.

250. PHOTOGRAPH OF ZEISS—VON OREL'S STEREO-AUTOGRAPH (1911 Model). Lent by Messrs. Carl Zeiss, Ltd.

In 1908, Lieut. E. von Orel, of the Military Geographical Institute, designed the first model of his stereo-autograph, by means of which the points of a stereo-photographic survey could be viewed in a Pulfrich stereo-comparator and automatically plotted, one by one, by the movements used to set the comparator. In this early model, which resembled Thompson's stereo-plotter, the altitudes of the various points had to be separately calculated, but in 1909 Messrs. Zeiss, in conjunction with von Orel, constructed a new model in which the contours could also be automatically plotted upon the plan. In 1911 the instrument represented in the photograph exhibited was evolved. It performs all the functions of the 1909 model and in addition permits the trace of any line upon the photographs, *i.e.*, upon the ground surveyed, to be plotted directly upon the plan ; thus contours, lines of rivers, roads, fences, etc., can all be automatically plotted by simply causing the index mark of the comparator to traverse such lines. Moreover,

with this model, the optical axis of the camera used in obtaining the two stereo-photographs need not be parallel or at right angles to the base of the survey, but must be horizontal.

The instrument consists of a stereo-comparator mounted upon the front of a massive base frame, and a plotting board fixed to the rear of the frame near its right-hand corner. A complicated framework composed of various rotating and traversing arms is connected to the comparator mechanism and carries the marking pencil, which automatically plots the plan, contours, etc., as the index mark of the comparator is set upon any point or line of the landscape viewed therein. The movements of the framework are controlled by the usual " direction," " distance " and " height " wheels, duplicated in the latter case by a foot pedal, so that all the necessary movements can be performed simultaneously. No scales to register the movements are necessary, as the points and lines are automatically plotted.

The whole instrument is mounted upon a table, and two operators are usually required to manipulate it. One operator controls the mechanism and the other sees that the pencil is recording properly and inserts names, figures, conventional signs, etc., on the plan.

The plates used are 18 cm. by 13 cm. The accuracy of surveying and plotting with this apparatus compares very favourably with that of the more usual methods, such as plane-tabling, and the speed is much greater. The instrument is more particularly adapted to large scale surveys, from 1 : 1,000 to 1 : 20,000.

(*See* " La stéréoautogrammétrie," by P. Corbin, in " Revue générale des Sciences." Vol. 25, 1914, p. 240.

" Stereographic Survey," by A. R. Hinks, F.R.S., in the " Geographical Journal," Vol. LIX, April, 1922, pp. 273–284.)

Inv. 1914–456. S.M. 911.

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Page

Admiralty, Lords Commissioners of the .. 15, 29, 31, 46, 47, 57, 62, 72, 73, 76, 78, 80, 81, 97, 98
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British Antarctic (Terra Nova) Expedition, 1910–13 .. 21
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French Government 9, 13
Geodetic Survey of Canada .. 10, 11, 14, 17
Lockyer, Prof. Norman, C.B., F.R.S. 88
Lyons, Capt. H. G., F.R.S. 22, 23, 38, 47
MacNamara, T., Esq. 20
Newton, F. & Co. .. 61, 68, 80, 97
Ogilvie, F. G., Esq., C.B. .. 20

Page

Ordnance Survey 9, 12, 13, 15, 24, 41, 42, 49, 71, 83–86, 88
Physical Department, Ministry of Public Works, Egypt .. 85
Pulkowa Observatory 24
Roberts, Evan, Esq. .. 19, 20, 68
Royal Observatory, Greenwich 89
Royal Society 24, 40, 48, 69
School of Military Engineering, Chatham 16
Shackleton, W., Esq., F.R.A.S. 60
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Survey of Egypt .. 11, 14, 25, 101
Survey of India 14
Symons, G. J., Esq., F.R.S. .. 50, 51
Troughton & Simms, Ltd. .. 51
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Waterhouse, Major G. G., R.E. 14, 27
Watson, W. & Sons, Ltd. .. 103
Watts, E. R. & Sons, Ltd. .. 44, 45, 46, 50, 78, 79
War Office 82
Worswick, Rev. T. P. W. .. 52
Zeiss, Carl, Ltd. .. 102, 103

INDEX.

	Page
Abney Level	47
Acetylene Signal Lamp	16
Adams, G.	21, 69
Adie Rangefinder	28, 31
Aerial Position Finder	81
Airy's Zenith Sector	88
Alidades, Plane Table	57–59
Anallatic Lens	34, 36, 78
Ancient Egyptian Levels	38
Aneroid Barometers	38, 51
Astrolabe	53, 87, 96
Astrolabe, Prismatic	90
Axis, Illumination of	72, 73, 76, 84–86, 89
Axis Level	48
Balance Level	38, 39
Bands, Measuring	22
Barometers, Aneroid	38, 51
Barometers, Levelling	37, 50–52
Barr and Stroud Rangefinder	28, 31, 32
Base, Hounslow Heath	8, 19, 24
Base, Lough Foyle	25, 84, 85
Base, Romney Marsh	24
Base, Salisbury Plain	25
Base Measuring Apparatus, Eimbeck Duplex	18, 26
Base Measuring Apparatus, Jäderin	18, 19, 25–27
Base Measuring Apparatus, Struve's	24
Beacons, Triangulation	14
Blakey Stadiometer	29
Boning Telescope	24
Borda	18, 54
Boscovitch	18
Box Sextant	80
Breithaupt's Compensation Level	43
British Antarctic Expedition, 1901	76
British Antarctic Expedition, 1910–13	21, 32
Broken Telescope	31, 82, 89
Brünner	18
Brunton Mining Transit	94
Bubble Level, Invention of	37
Bubble Tubes	49
Burel Reflecting Level	39, 40
Burnier's Compass-Clinometer	63
Burt Solar Attachment	77
Cary	72
Casella's "Pocket-Altazimuth"	63
Chains, Measuring	22, 24
Chorobates	36
Chronograph	87
Chronometer, Invention of	96
Circumferentors	64–68
"Cleps" Tacheometer	34
Clinometers	39, 40, 46–48, 61, 63
Colby's Compensation Bars	18, 24
Compass-Clinometer, Burnier's	63
Compass-Clinometer, Casella's	63
Compasses, Surveying	59–64
Compensation Bars, Colby's	18, 24
Compensation-Level, Breithaupt's	43
Compensation Microscopes, Colby's	18, 25
Cooke's Reversible Level	43
Cross Staff	56
De Lisle's Reflecting Clinometer	40
Dials, Miner's	91–95
Diaphragm, Tacheometric	33–35, 37, 55
Digges, Thos.	53
Dioptra, Hero's	28, 36, 53
Dip of the Horizon	80, 99
Dip Sector	80
Distance Meter, Stuart's	29
Dollond	51, 56, 60
Dray Traverse Mark	11
Dumpy Level	44
Duplex Base Apparatus, Eimbeck's	18, 26
Early Egyptian Land Measurers	22
Early Theodolites	64–68
Eccentric Telescope	75, 78, 93
Eckhold's Omnimeter	35
Eimbeck Duplex Base Apparatus	18, 26
Electric Signal Lamp	17
Enclosed Circles on Theodolites	71, 74, 76–80, 94
Equal Altitude Instrument	90
Everest Theodolites	71, 85
Field Clinometer	47
Forbes's Stereoscopic Rangefinder	29, 32
Gascoigne	33, 53
Gauss, C. F.	8, 19, 24
Gautier Telemeter	28, 30
Gentilli's Tacheometer	34
Gradienter Scale	77, 78
Graphometers	65–67
Groma	53, 55, 56
Gunter's Chain	22
Hedley Dial	93
Heliographs	15, 16
Heliotropes	15, 16
Hero of Alexandria	19, 28, 36, 53
Hooke	34
Hounslow Heath Base	8, 19, 24
Huygens	37, 39, 69, 75, 93
Hypsometers	37, 52

	Page
Indian Clinometer	48
Internal Focussing Lens	44, 46, 55, 78, 79, 80, 94
Invar	19, 26, 27, 45, 46, 50
Ipodimeter	65
Jäderin Base Apparatus	18, 19, 25–27
Jähns's Polymeter	59
Jeffcott Direct-Reading Tacheometer	35
Johnson Plane Table	58
Jones, Thos.	72, 80
Jones, W. & S.	68, 92
Kater's Mirror Compass	60
Labbez Telemeter	28, 30
Lamps, Signal	16, 17
Latitude, Determination of	77, 87–90, 96
Lean's Dial	92
Level, Axis	48
Levelling Barometers	37, 50–52
Levelling Staves	37, 49, 50
Levels	36–48
Levels, Abney	47
Levels, Precise	46
Lesuerre Heliograph	16
Liquid Prismatic Compass	62
Longitude, Determination of	87, 90, 96
Lough Foyle Base	25, 84, 85
Magnetic Needle, first applied to Mine Surveying	90
Magnetometer, Mine	95
Marine Sextants	97, 99
Marks, Bench	12–14
Marks, Traverse	9–11
Marks, Triangulation	9–11
Measuring Bands	22
Measuring Chains	22, 24
Measuring Rods	23–26
Measuring Tapes	23–27
Measuring Wedge	23
Mekometer, G. S.	28, 31
Microscopes, Reading	82–86
Mine Magnetometer	95
Mine Theodolites	93
Miner's Dials	91–95
Mining Transit, Brunton	94
Mirror Compass, Kater's	60
Nordenfelt Sextant	99
Omnimeter, Eckhold's	35
Optical Opposites	56, 57
Optical Squares	56, 57
Paget Angle Sextant	81
Pedometers	19, 21
Perambulator	21
Periscope Theodolite	82
Photo-Theodolites	101, 102
Picard, J.	17, 18, 37, 54
Plane Table Alidades	57–59
Plane Tables	57, 58
Pocket-Altazimuth, Casella's	63
Polymeter, Jähns's	59
Porro	34
Potter's Prismatic Alidade	59
Praetorius, J.	53
Precise Levels	46
Prismatic Astrolabe	90
Prismatic Compasses	60–62
Ptolemy	86, 87, 95
Qassaba Measuring Rod	23
Quadrant, Surveying	66
Quick-Levelling Socket, Johnson	58
Quick-Levelling Tripod Head	83
Ramsden, J.	24, 54, 70, 83, 84, 87, 88
Ramsden's Steel Chain	24
Ramsden's 3-ft. Theodolite	83, 84
Rangefinders	28–33
Reading Microscopes	82–86
Reflecting Clinometer, De Lisle's	40
Reflecting Level, Burel	39, 40
Reflecting Sextant	97
Reversible Tube-Level	43, 74
Reversible Level, Cooke's	43
Rods, Measuring	23–26
Romney Marsh Base	24
Rope Stretchers	22
Roy, General	19, 24
Salisbury Plain Base	25
Schmalcalder's Prismatic Compass	60–62
Self-Centring Tribrach	11
Sextant, Angle	81
Sextant, Box	80
Sextants, Marine	97, 99
Shifting Centre	77, 78, 80, 82, 91, 94
Shifting Centre Tripod Head	83
Signal Lamps	16–17
Sisson, J.	54, 68
Sledge Meter	21
Snell, W.	17
Solar Attachment, Burt	77
Stadiometer, Blakey	29
Station Keepers	98
Station Pointer	98
Staves, Levelling	37, 49, 50
Staves, Tacheometric	36
Stereo-Autograph, Zeiss-Von Orel	103
Stereo-Comparator, Zeiss-Pulfrich	102
Stereo-Plotter, Thompson	103
Stereoscopic Rangefinders	28, 29, 32
Struve, W.	24, 87, 89
Stuart's Distance Meter	29

	Page
Tacheometers	33–36
Tacheometric Staff	36
Tape Stretching Apparatus	27
Tapes, Measuring	23, 27
Telemeters	28, 30, 31
Telescope, first applied to Surveying Instruments	54
Telescope, Boning	24
Telescope, Zenith	89
Telescopic Alidade	58, 61
Thales of Miletus	28, 36
Theodolites, Altazimuth	68–80
Theodolites, Early	64–68
Theodolites, Everest	71, 85
Theodolites, Geodetic	83–86
Theodolites, Micrometer	79, 83
Theodolites, Mine	93
Theodolites, Photographic	101, 102
Theodolites, Transit	72–80, 84–86
Thévenot, M.	37, 54
Transit Instruments	89, 90
Transit Theodolites	72–80, 84–86
Traverse Marks	9–11
Triangulation Marks	9–11
Triangulation Beacons	14
Tribach, Self-centring	11
Troughton, E.	70, 87, 88
Vernier, P.	54
Water-level	37
Watkin Aneroid Barometer	51
Watkin Clinometer	48
Waywiser	21
Wright, Thos.	67, 68
Y-Levels	45
Zeiss Level	44
Zeiss Photo-Theodolite	102
Zeiss Rangefinder	28
Zeiss Stereo-Autograph	103
Zeiss Stereo-Comparator	102
Zenith Sectors	88
Zenith Telescope	89

LIST OF MUSEUM INVENTORY NUMBERS of objects with Corresponding Catalogue Serial Numbers.

Inventory No.	Catalogue No.	Inventory No.	Catalogue No.	Inventory No.	Catalogue No.
1857–25	91	1899–52	144	1913–258	88
1865–5	209	1900–90	83	1913–560	65
1865–6	238	1900–153	183	1913–571	184
1865–7	156	1900–154	96	1913–572	52
1872–78	53	1900–155	95	1914–103	222
1872–79	155	1900–156	61	1914–107	4
1872–80	186	1900–157	62	1914–108	5
1875–25	48	1900–167	120	1914–109	28
1876–1192	196	1905–155	152	1914–110	29
1876–1193	195	1906–40	50	1914–111	51
1876–1194	197	1907–65	128	1914–149	23
1876–1195	198	1907–66	231	1914–150	24
1876–1196	102	1907–67	130	1914–151	20
1876–1197	233	1908–118	176	1914–152	19
1876–1198	103	1908–119	177	1914–153	21
1876–1200	146	1908–120	230	1914–154	3
1876–1201	64	1908–122	168	1914–155	22
1876–1202	223	1909–137	189	1914–179	79
1876–1203	217	1909–138	185	1914–180	78
1876–1204	219	1909–139	77	1914–219	86
1876–1205	82	1909–140	150	1914–220	114
1876–1206	190	1910–125	181	1914–238	40
1876–1207	208	1910–126	75	1914–257	58
1876–1208	141	1911–151	74	1914–258	59
1876–1209	71	1911–152	139	1914–259	60
1876–1211	63	1911–154	140	1914–293	76
1880–195	171	1911–155	38	1914–297	249
1880–198	148	1911–157	157	1914–304	227
1880–199	173	1911–158	193	1914–305	35
1880–200	170	1911–159	192	1914–376	36
1880–201	90	1911–160	191	1914–388	66
1880–202	167	1911–161	199	1914–389	67
1883–14	225	1911–172	241	1914–390	68
1883–118	89	1911–173	242	1914–422	123
1887–62	116	1911–174A	112	1914–423	25
1889–21	142	1911–174B	113	1914–424	26
1889–22	136	1911–180	153	1914–425	37
1890–55	81	1911–182	44	1914–456	247, 248, 250
1890–55	85	1911–183	92		
1891–24	224	1911–220	210		
1892–9	172	1912–197	98	1914–553	214
1892–21	97	1912–198	99	1914–554	
1893–119	129	1912–199	100	1914–555	
1893–133	127	1912–200	45	1914–561	174
1893–134	126	1912–243	149	1914–735	131
1893–147	200	1912–244	57	1914–741	201
1893–148	162	1912–245	69	1914–742	145
1893–149	132	1912–308	178	1914–829	39
1894–106	169	1913–254	115	1914–845	54
1895–48	221	1913–256	101	1914–846	55
1895–49	188	1913–257	175	1914–847	56

LIST OF MUSEUM INVENTORY NUMBERS of objects with Corresponding Catalogue Serial Numbers—*continued.*

Inventory No.	Catalogue No.	Inventory No.	Catalogue No.	Inventory No.	Catalogue No.
1914–894	187	1920–82	7	1921–733	105
1914–895	49	1920–84	239	1922–41	158
1915–399	72	1920–88	204	1922–42	117
1916–6	151	1920–89	240	1922–43	232
1916–64	160	1920–131	229	1922–44	159
1916–77	42	1920–384	15	1922–205	205
1916–81	47	1920–385	17	1922–206	109
1916–82	43	1920–386	2	1922–440	107
1916–83	46	1920–387	18	1922–441	110
1917–22	138	1920–388	1	1922–442	108
1917–38	111	1920–389	33	1922–443	106
1917–39	87	1920–442	80	1922–444	203
1917–77	207	1920–583	211	1922–445	206
1917–78	154	1920–627	14	1922–446	124
1917–104	182	1920–628	30	1922–467	125
1917–105	194	1920–629	31	1922–723	32
1917–106	143	1920–630	13	1922–724	11
1917–107	122	1920–655	70	1922–725	12
1917–113	245	1921–81	137	1922–726	10
1918–123	165	1921–306	34	1923–10	41
1918–124	164	1921–360	16	1923–395	135
1918–126	166	1921–479	220	1923–405	244
1918–240	179	1921–513	226	1923–414	161
1919–331	93	1921–514	228	1923–492	133
1919–415	212	1921–519	94	1923–493	134
1919–416	163	1921–556	218	1924–103	246
1919–495	213	1921–558	234	1924–465	235
1920–22	243	1921–559	216	1924–466	147
1920–66	73	1921–560	104	1925–3	236
1920–76	27	1921–561	215	1925–4	118
1920–77	9	1921–563	121	1925–5	119
1920–78	8	1921–588	180	1925–7	84
1920–81	6	1921–732	202	1925–8	237

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